MISSION TO THE OUTER SOLAR SYSTEM p. 24

MARCH 2021

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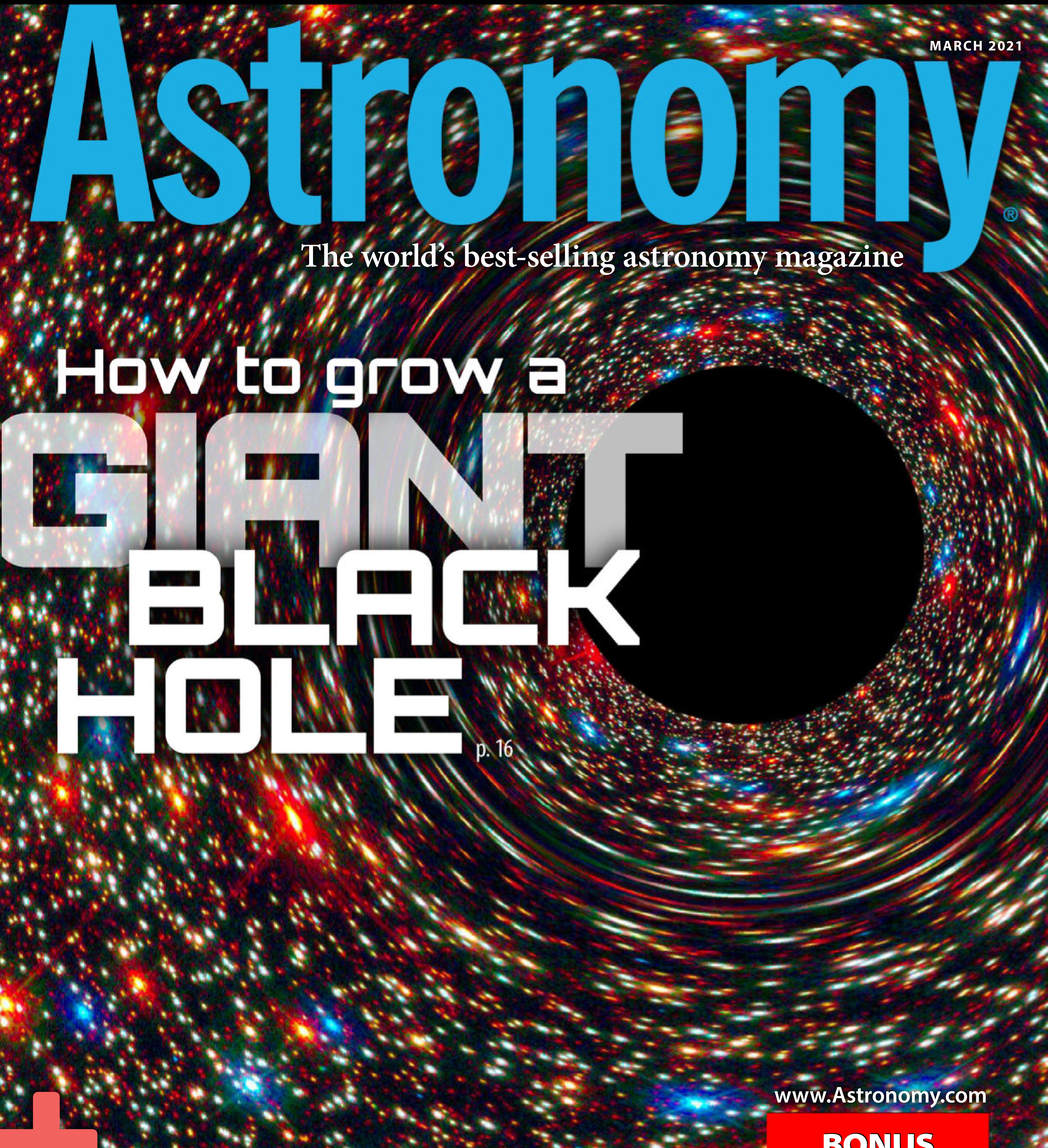

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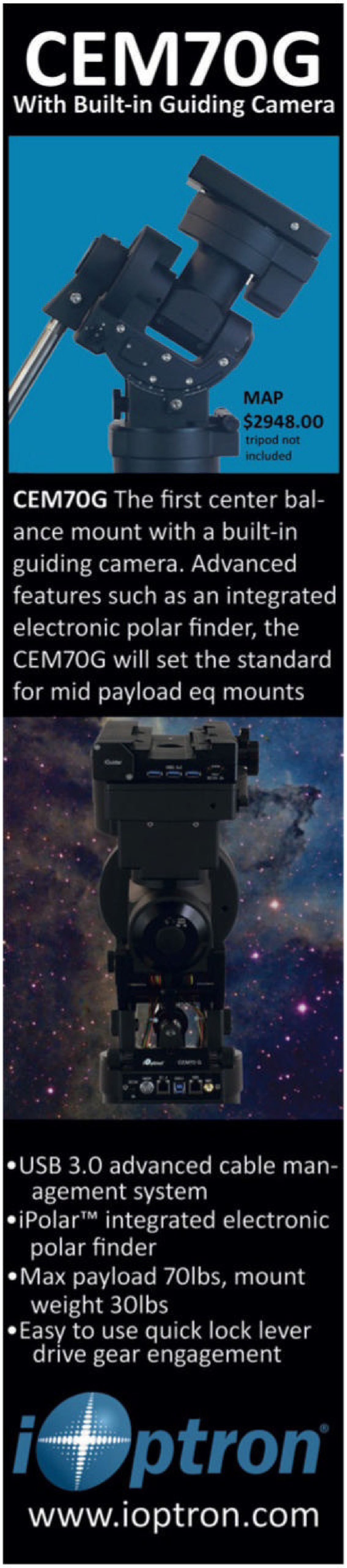
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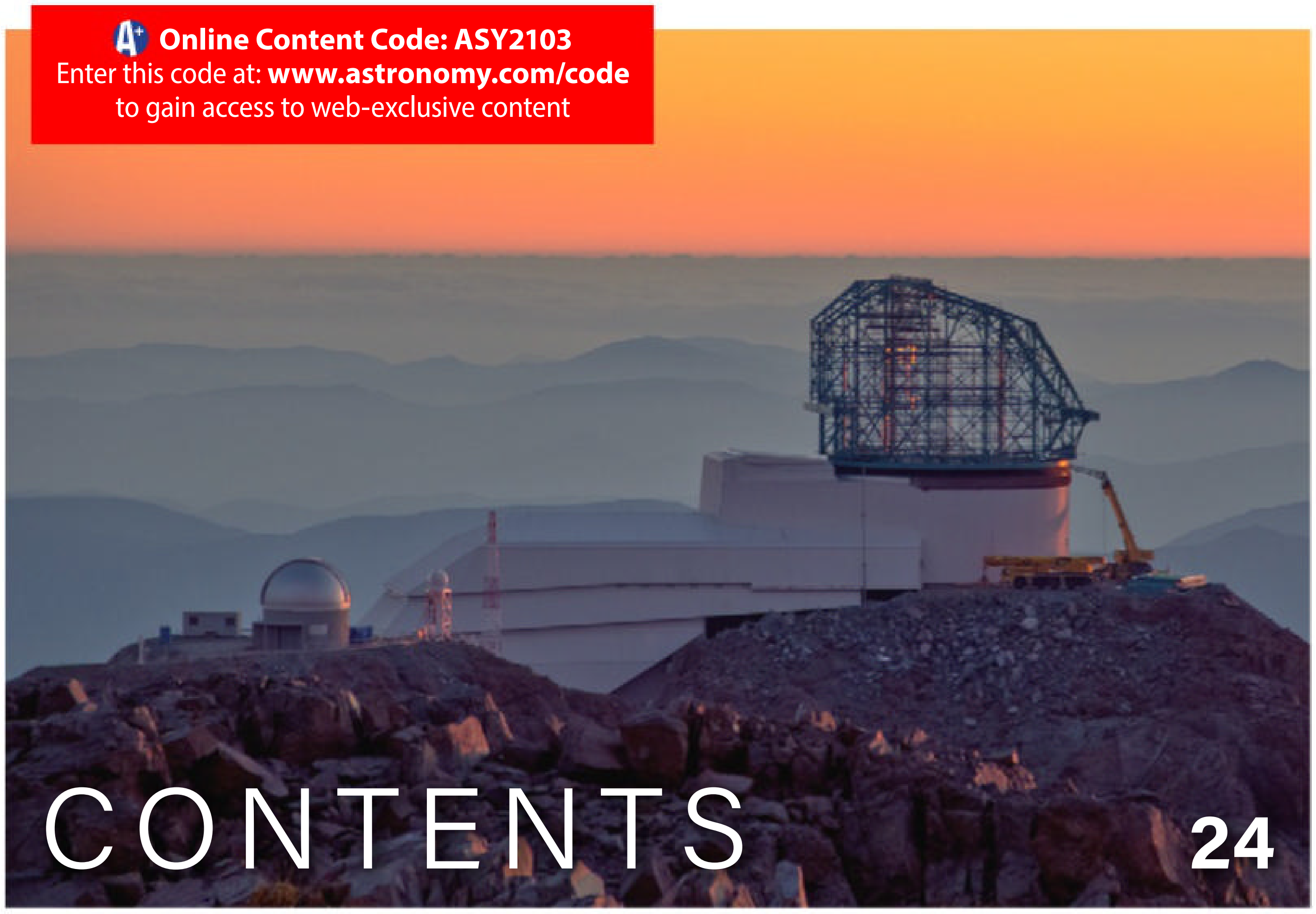

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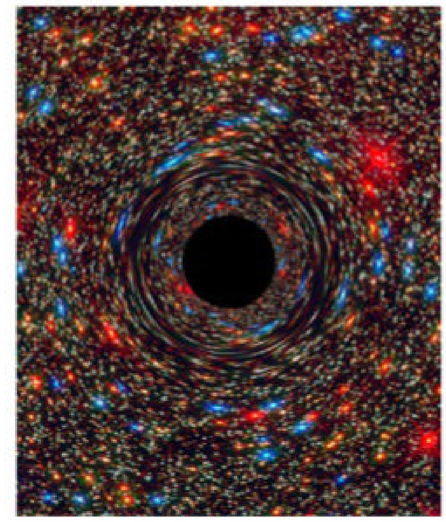

ON THE COVER

Black holes fascinate us, but their rapid early growth poses a dilemma for astronomers. NASA, ESA, AND D. COE, J. ANDERSON, AND R. VAN DER MAREL (SPACE TELESCOPE SCIENCE INSTITUTE)

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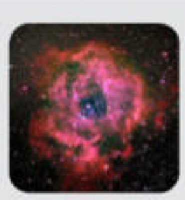
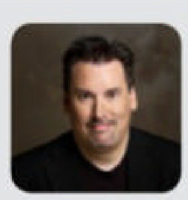


Picture of the Day
Gorgeous photos from our readers.



Dave's Universe
The inside scoop from the editor.

My Science Shop
Perfect gifts for your favorite science geeks.

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FROM THE EDITOR

The most fascinating monsters

A quasar harboring a supermassive black hole in its center gleams brilliantly in the early universe.
ESO/M. KORNMESSER

When you click on the TV and escape this crazy world with a film, maybe you're a sci-fi fan. Do you glimpse Godzilla? Revere zombies or Terminators? Whichever way you go, you might be overlooking the most terrifying monsters of them all: black holes.

Encountering a live black hole would be a harrowing experience — at least briefly. Depending on the black hole's mass, it would most likely pull you into a miles-long string of protons — "spaghettify" you — as you fell into the event horizon, making movie monsters pale in comparison.

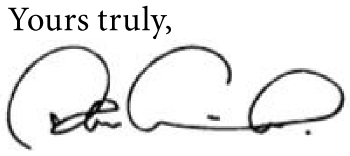
The physics of black holes has been worked out only in the last generation or two, but the concept goes back a very long time. In 1783, the English natural philosopher John Michell proposed the existence of so-called dark stars, regions in the universe with such intense gravity that not even light could escape their clutches. Yet hard evidence for the existence of black holes was very slow in arriving. The first good stellar black hole candidate, Cygnus X-1, was discovered in 1964.

In 1974, two close friends, Stephen Hawking and Kip Thorne, jokingly bet on whether Cygnus X-1 would or wouldn't turn out to be a black hole. Only in 1990 did Thorne win the bet, when Cygnus X-1 became the first confirmed black hole.

Soon thereafter, astronomers began to discover supermassive black holes in the centers of galaxies, largely by using the Hubble Space Telescope. John Kormendy, Luis Ho, and their collaborators found many of the first. Now we know that most all galaxies (except for dwarfs) host a central black hole.

Bob Naeye's story on page 16 describes the recent finds of supermassive black holes in the very young universe. I hope you'll enjoy reading the newest chapter in the quest to understand the most fearsome monsters in the cosmos.

Yours truly,



David J. Eicher
Editor

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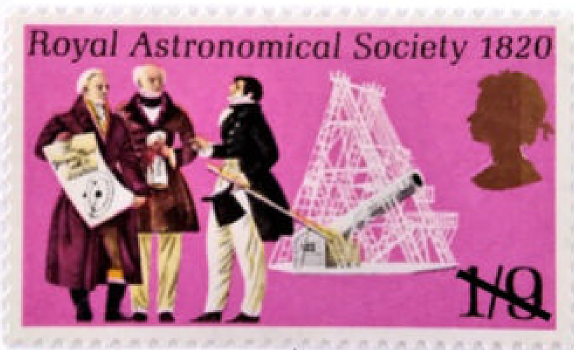


Queen Elizabeth's profile, at right, appears on all U.K. stamps. KATRIN RAYNOR

Astronomy's leading lady

I would like to point out that, on the stamp commemorating the 150th anniversary of the Royal Astronomical Society (from your November story, "Collect the cosmos in stamps"), there are four people depicted: William Herschel, John Herschel, Francis Baily, and off to the right the silhouette is Caroline Herschel. She was William's right hand, John's first teacher of astronomy, the first woman to be salaried as an astronomer, and the discoverer of eight comets; rewrote Flamsteed's catalog correcting his mistakes; and made it easier for astronomers to view the night sky. **—K. Lynn King**

Author Katrin Raynor responds: *While Caroline Herschel is certainly worthy of recognition, the profile on the stamp is the head of Queen Elizabeth II.*

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Science meets art

Thank you for your portrait of Galileo as an artist in your November issue. His work both as an artist and a scientist helped him excel in both fields. It is believed that he saw Neptune twice while looking at Jupiter, once on December 28, 1612, and then on January 27, 1613. This can be determined now because his very careful drawings show Neptune in the right places for those dates. Unfortunately, he mistook it for a fixed star and Neptune wasn't recognized as a planet until 1846. **—Ken Elstein,** Belchertown, MA


GALILEO GALILEI (1564-1642), OIL PAINTING AFTER JUSTUS SUSTERMANS, 1635. COURTESY OF THE WELLCOME COLLECTION, ATTRIBUTION 4.0 INTERNATIONAL (CC BY 4.0)

Crossing fields

I always appreciate Jeff Hester's articles. I was really pleased with the September 2020 article "Learning the hard way." Jeff, who is an astrophysicist, explained the biology, biochemistry, and biophysics of the coronavirus in a very lucid and effective manner. I greatly respect someone who is willing to learn other fields of science outside of their own discipline, as was the case here. Thank you for encouraging science education to the wider public! We need more of that! **—Wolfgang Golser,** Tucson, AZ

QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH

SNAPSHOT

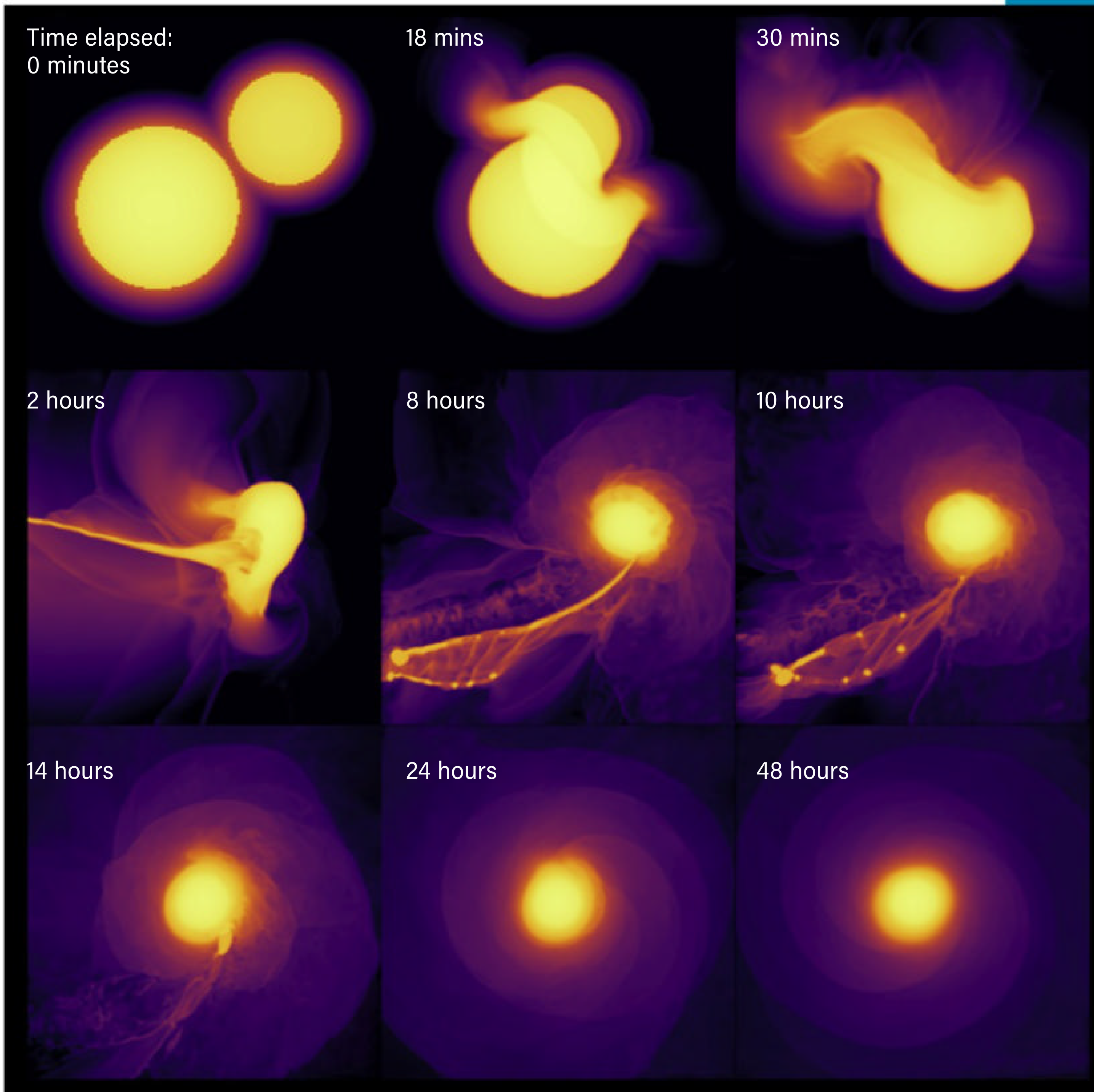
MAKING THE MOON

A new simulation shows the impact that created our natural satellite.

Researchers think the Moon was formed when Earth was struck by a Mars-sized body, known as Theia, early in the solar system's history. These snapshots from a simulation published October 29 in *The Astrophysical Journal Letters* capture the terrifying and beautiful dynamics of such a collision.

In the first three frames (top row), which cover a time frame of 30 minutes, the impactor gouges out a massive chunk of Earth, blasting debris into space. Over the following 10 hours (middle row), much of that debris rains back down to Earth, including huge fragments that have completed as much as half an orbit. Within 48 hours after the impact (bottom row), the remaining orbital debris has begun to form a disk of material that surrounds Earth. These remnants will eventually coalesce, forming the Moon.

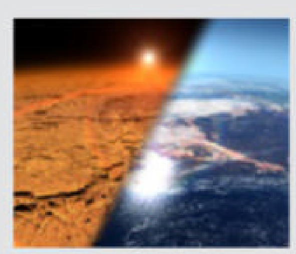
— MARK ZASTROW



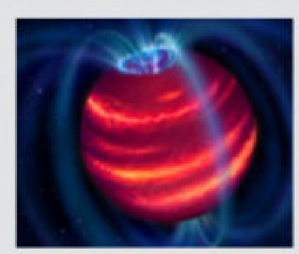
MULLEN AND GAMMIE (2020)/SIMULATIONS AND ANALYSIS PERFORMED WITH ATHENA++ AND YT WITH SUPPORT FROM NASA/SUPERCOMPUTER TIME PROVIDED BY NASA'S PLEIADES, TACC'S STAMPEDE2 (UNIVERSITY OF TEXAS AT AUSTIN), NCSA'S BLUE WATERS (UNIVERSITY OF ILLINOIS: URBANA-CHAMPAIGN). BOTTOM FROM LEFT: NASA; NASA'S GODDARD SPACE FLIGHT CENTER; ASTRON/DANIELLE FUTSELAAR

HOT BYTES

SWITCHING PARTNERS
The rocket that launched NASA's Surveyor 2 probe to the Moon in 1966 went on to orbit the Sun — until November 2020, when Earth recaptured it. After temporarily orbiting our planet, it will return to circling the Sun in March 2021.



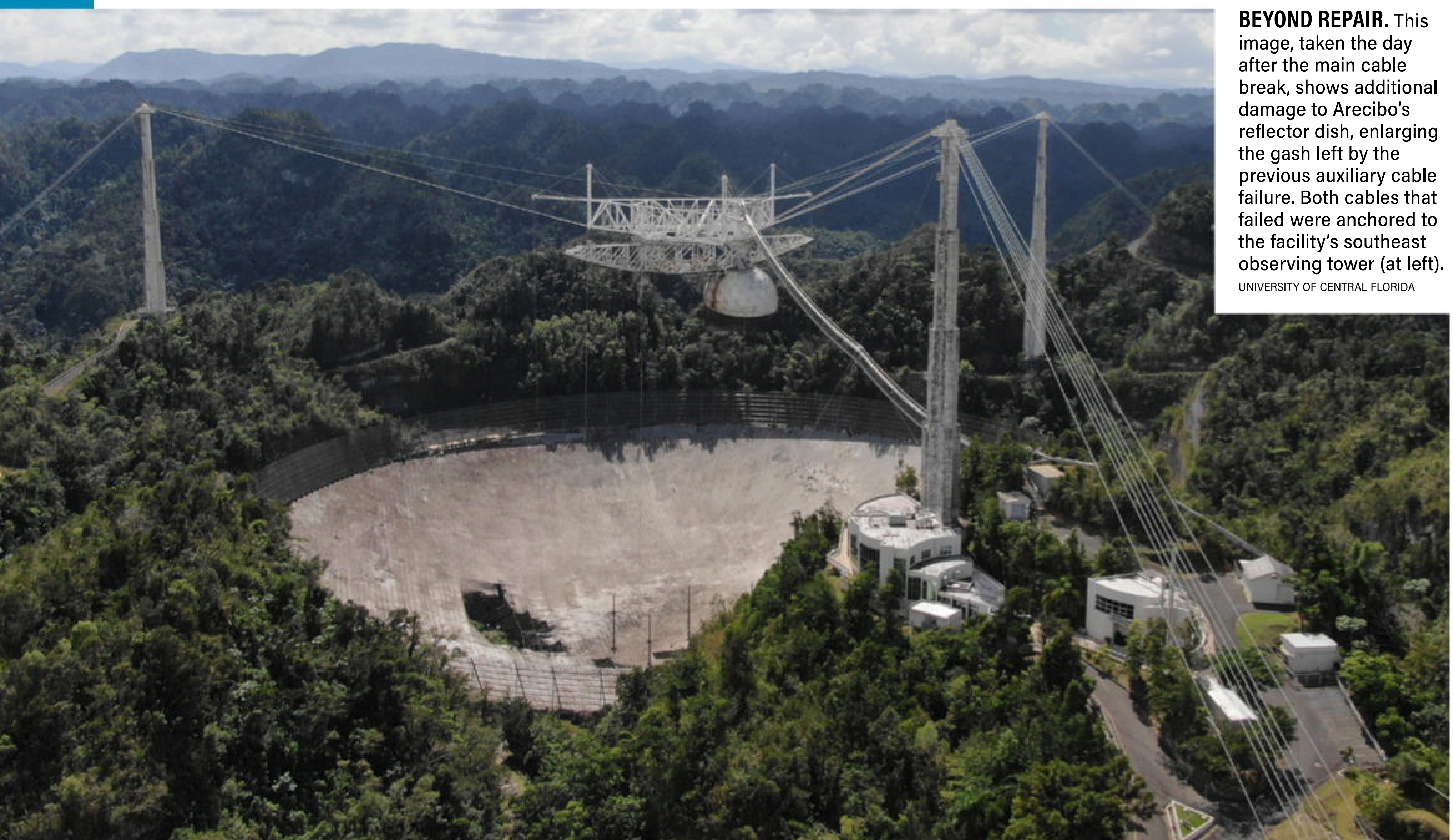
GREAT HEIGHTS
New research shows that dust storms on Mars can loft water vapor high into the atmosphere, where it escapes or is destroyed by radiation. This could explain how the Red Planet has lost — and continues to lose — its water.



FIRST FOUND
Astronomers using the Low Frequency Array in Europe have detected a brown dwarf's weak magnetic field, a first for any radio telescope. This paves the way to finding more such objects, which have masses between planets and stars.

ARECIBO COLLAPSES AFTER CABLE FAILURES

Astronomers are mourning the loss of the iconic radio telescope and paying tribute to its legacy.



BEYOND REPAIR. This image, taken the day after the main cable break, shows additional damage to Arecibo's reflector dish, enlarging the gash left by the previous auxiliary cable failure. Both cables that failed were anchored to the facility's southeast observing tower (at left). UNIVERSITY OF CENTRAL FLORIDA

After 57 years of cutting-edge research and pop culture fame that inspired generations of scientists, the legendary Arecibo radio telescope in Puerto Rico was destroyed on December 1 when its receiving platform collapsed and came crashing down onto the dish below.

A series of cable failures doomed the massive facility. First, on August 10, an auxiliary cable that helped suspend the 900-ton receiving platform slipped out of its socket on one of three support towers that surround the observatory, tearing a 100-foot (35 meters) gash in the dish.

Then, on November 6 — just days before repairs were set to begin — one of the main cables attached to that same support tower snapped, likely due to the increased load it was bearing.

That put the structure at risk of total collapse — and therefore beyond repair. Engineers from outside firms hired to work on Arecibo concluded that losing another cable would probably trigger a cascading catastrophic failure.

The U.S. National Science Foundation (NSF), which owns the facility, announced November 19 it would decommission the radio telescope, saying it could not be safely repaired without risking the lives of workers.

"I don't think anyone understood that, clearly, the cable had deteriorated much below just those broken wires," said Ashley Zauderer, NSF's Arecibo program officer, at a press conference.

But before demolition plans were finalized, the receiving platform collapsed on its own the morning of December 1. No one was injured, said NSF, but the observatory's education center took significant damage from falling cables.

The impact of the platform was heard and felt around the area. Drone footage

NASA/JPL-CALTECH

JUPITER'S LUMINESCENT MOON

As Europa orbits Jupiter, it endures constant radiation from its host planet's magnetic field. Night and day, energy rains onto Europa, making the moon's ice-and-salt surface glow in the dark. Researchers also believe the nightside glow holds clues to whether Europa could sustain life. To answer that question, scientists looked at the way organic material reacted to similar blasts of radiation in the lab and uncovered something unexpected: variation in how different ice-salt compositions glowed. This means that Europa likely glows brighter in some spots than others, which can be seen in this artist's illustration. – CAITLYN BUONGIORNO

showed the crumpled Gregorian dome, which housed the telescope's sensitive receiving equipment, and the remains of an access platform on a hillside where it crashed through the dish. Support cables were strewn across the valley.

A CRUSHING BLOW

Arecibo's loss left scientists reeling. "I'm pretty crushed," Scott Ransom, an astronomer at the National Radio Astronomy Observatory and member of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) project, tells *Astronomy*. NANOGrav uses Arecibo and the Green Bank Telescope (GBT) in West Virginia to search for signs of gravitational waves by looking for telltale disruptions in the timing of radio signals coming from pulsars.

"This is a huge blow to NANOGrav, as about one-half of our gravitational wave sensitivity comes from Arecibo," Ransom says. "And because it is so much more sensitive than GBT, it will be impossible to replicate the timing precision we get."

Plus, Arecibo had the unique capability to not only receive radio signals but also transmit them, notes Yvette Cendes, a radio astronomer at the Harvard–Smithsonian Center for Astrophysics. "So you're out of luck for radar mapping of planets and asteroids if that was your field," says Cendes.

Scientists around the world took to social media, using the hashtag #WhatAreciboMeansToMe, to share stories of how Arecibo had inspired them or affected their careers. Some of the most heartfelt tributes came from Puerto Rican researchers, including in fields extending well beyond astronomy.

"Every Puerto Rican learns about Arecibo Observatory," tweeted Vivian Irizarry Gatell, a hematology/oncology fellow at the University of Florida. "It showed me that I could be a great scientist like my ancestors. … [Its loss] is a tragedy for STEM in Puerto Rico." – M.Z.

AFTER THE FALL. The steel carcass of the receiving platform and an access platform lie in a tangled heap across the remains of the reflector dish. UCF

QUICK TAKES

STAYING HYDRATED
The Stratospheric Observatory for Infrared Astronomy — NASA's Boeing 747-borne infrared telescope — has found traces of water ice on the Moon's sunlit surface. Researchers suspect micrometeorite fragments in the lunar soil protect the ice from turning to gas in sunlight.

BIRTH OF THE BULGE
A survey of the Milky Way's central bulge by the Cerro Tololo Inter-American Observatory in Chile found that most of its stars were born in a single burst of star formation more than 10 billion years ago — not in several spurts, as previously suggested.

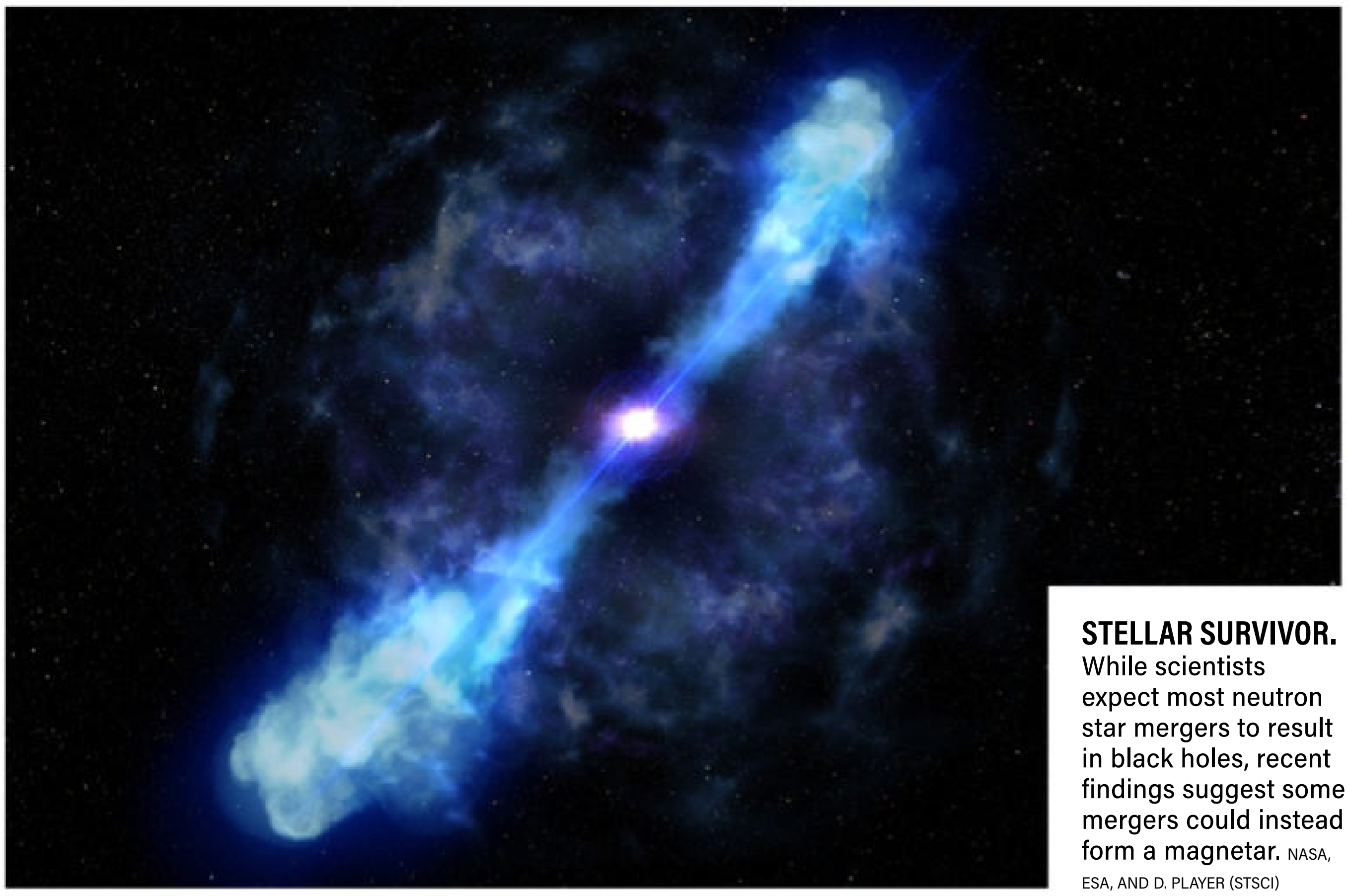
NIGHT LIGHTS
In Tucson, Arizona, streetlights account for no more than 14 percent of light pollution, according to a 2019 experiment in which the city dimmed them for several nights. This suggests additional light sources, such as signs and sports fields, must be curbed to preserve dark skies.

ROCKY WITH A CHANCE OF ROCKS
The Earth-sized exoplanet K2-141 b has an atmosphere of rock vapor, according to simulations. With surface temperatures of 5,400 degrees Fahrenheit (3,000 degrees Celsius), its lava oceans evaporate, condense, and rain rocks.

HIGH HONOR
The 64-meter Parkes radio telescope in Australia has been given an Indigenous name by elders of the Wiradjuri, the Aboriginal people native to the area. The name, *Murriyang*, means "Skyworld," which is the mythological home of the Wiradjuri creator spirit Biyaami.

GETTING HEATED
The average temperature of galaxy clusters in the universe is nearly 4 million F (2.2 million C) — three times hotter than it was 8 billion years ago, according to new research. The heating is due to friction generated as clusters pull in gas over time. – M.Z.

Magnetic star born from a colossal collision



STELLAR SURVIVOR. While scientists expect most neutron star mergers to result in black holes, recent findings suggest some mergers could instead form a magnetar. NASA, ESA, AND D. PLAYER (STSCI)

» When stars collide, the result is often explosive. That's especially true when those objects are a pair of super-dense stellar remnants known as neutron stars. These exotic objects cram nearly twice the mass of the Sun into a space about the size of Chicago. And when two neutron stars merge, the resulting explosion — called a kilonova — glows 100 million times brighter than the Sun, unleashing more energy in a few seconds than our star will produce during its 10-billion-year lifetime.

The light from one such collision reached Earth on May 22, 2020. After traveling nearly 5.5 billion light-years, the brilliant flash was first detected by NASA's Neil Gehrels Swift Observatory. Astronomers quickly turned other telescopes to the aftermath of the explosion. Viewing this glowing cloud of dust and gas, the Hubble Space Telescope spotted something strange in infrared light: The afterglow was 10 times brighter than anticipated, which meant that the object formed in the collision was feeding additional energy into the gas cloud.

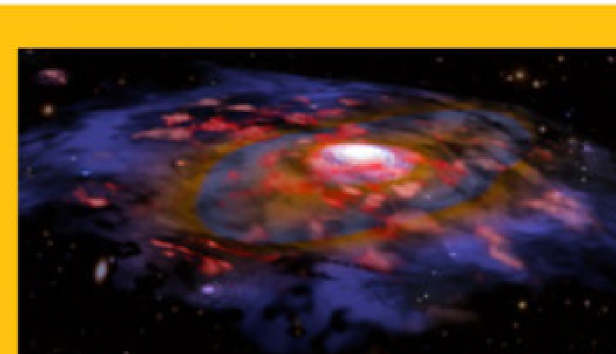
This is surprising because, until now, scientists had believed a neutron star merger formed an unstable, heavy neutron star that only lasted for a few milliseconds before collapsing into a black hole. But a black hole can't quite explain the extra energy Hubble saw.

However, a magnetar — a rapidly rotating neutron star with an incredibly powerful magnetic field — could be injecting energy into the gas. The researchers say that the magnetic field lines anchored to such stars are whipped around at about 1,000 times a second and, in this case, may be depositing extra energy into the debris left by blast, making it glow brighter.

Typically, magnetars are born like their less magnetic cousins — from the explosive deaths of massive stars. However, these findings suggest that at least some magnetars can form during neutron star mergers — something astronomers had never seen before.

To determine if this is the case, scientists will need to keep their eyes trained on this area of the sky. If a magnetar really did form, then within a few years, the material ejected during its birth will begin shining at radio wavelengths, opening new doors for probing the origins of such objects. – C.B.

MATURE GALAXIES POPULATED THE EARLY UNIVERSE



ANCIENT DUST. This artist's concept shows the dust (blue/brown) and gas (red) that a recent study observed in some of the universe's earliest galaxies. B. SAXTON NRAO/AUI/NSF, ESO, NASA/STSCI; NAOJ/SUBARU

Most of the galaxies in the universe formed when the cosmos was young. At that time, there was very little dust and almost no elements heavier than hydrogen and helium. Astronomers believe that dust and heavy elements were eventually injected into galaxies by dying stars.

A recent survey from the Atacama Large Millimeter/submillimeter Array (ALMA) suggests that early galaxies underwent a growth spurt between 1 billion and 1.5 billion years after the Big Bang, when the universe was only 10 percent its current age. At this early time, astronomers didn't expect galaxies to have much time to build stars, let alone lose them. But scientists found that out of 118 galaxies, about 20 percent were very dusty, showing that they had evolved faster than expected.

How these galaxies grew up so quickly is still a mystery, but it may be related to the environment they reside in. To learn more, astronomers want to obtain more detailed observations. – C.B.

CREW-1 USHERS IN "NEW ERA" OF SPACEFLIGHT

RESILIENCE. SpaceX's Crew Dragon capsule — carrying NASA astronauts Shannon Walker, Victor Glover, and Michael Hopkins, as well as JAXA astronaut Soichi Noguchi — blasts off from historic Launch Complex 39A at Kennedy Space Center in Florida. NASA/JOEL KOWSKY

COMMERCIAL SPACEFLIGHT, a feat that once seemed impossible, is now on the verge of becoming routine. Humanity took one more step toward that future on November 15, when a SpaceX Crew Dragon capsule, riding atop a Falcon 9 rocket, blasted off from NASA's Kennedy Space Center in Florida. By the following night, its four astronaut passengers had docked with and transferred to the International Space Station (ISS), kicking off the first official mission of NASA's Commercial Crew Program. It also marked the second crewed launch for SpaceX in 2020.

The spacefaring quartet will spend the next six months carrying out scientific experiments alongside fellow astronauts and cosmonauts already aboard the space station, bringing the total number of ISS crew members to seven.

This particular Crew Dragon capsule is named *Resilience*, a nod to the extreme difficulties that were overcome to make the historic launch happen, including the COVID-19 pandemic. "This is the culmination of years of work and effort from a lot of people," said Benji Reed, director of crew mission management at SpaceX, at a briefing before the launch.

The difficult journey to Crew-1's launch has stretched out over nearly a decade. When NASA formally retired the Space Shuttle Program in 2011, the agency shifted its focus to getting astronauts to the Moon and Mars, with the hopes of paying private companies to ferry people and cargo to the space station.

Initially, NASA thought the first Commercial Crew Program flight would happen in 2016. But SpaceX and Boeing, the companies hired for the job, were hit by a seemingly unending series of delays.

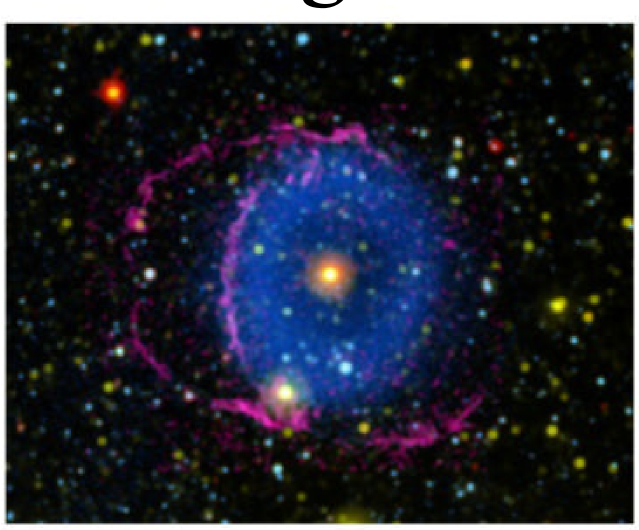
However, over the past two years, SpaceX has slowly overcome its early challenges. In May, SpaceX's Crew Dragon spacecraft successfully carried two NASA astronauts to the ISS on a demonstration mission, called Demo-2. That trip was the first time that astronauts had traveled into orbit on a private spacecraft.

Now, nine years after the last space shuttle flew, America finally seems to have a reliable homegrown ride into orbit again. And as important as this milestone was for NASA, it also opens up the solar system for SpaceX. NASA has formally certified the company to fly astronauts into orbit, which means SpaceX can begin launching tourists to space, too. – ERIC BETZ

30

Roughly the total amount of space data, in terabytes per day, transmitted to the ground by Earth-orbiting NASA satellites. By 2030, NASA hopes to hand off much of this load to commercial satellites, freeing government satellites for research and development work.

Mystery of the Blue Ring solved

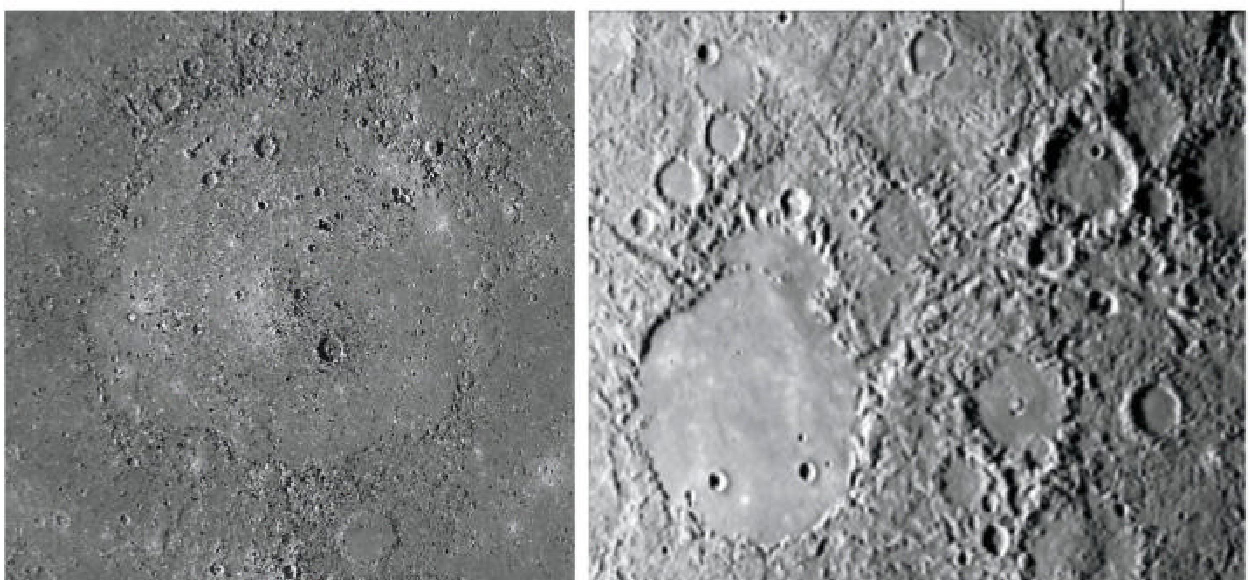


NASA/JPL-CALTECH/M. SEIBERT (CARNEGIE INSTITUTION FOR SCIENCE)/K. HOADLEY (CALTECH)/GALEX TEAM

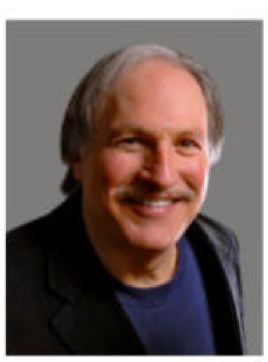
The Blue Ring Nebula was first spotted in 2004 by NASA's Galaxy Evolution Explorer. But astronomers weren't sure how its strange, ringed structure had formed — until now. A paper published November 18 in *Nature* used comprehensive observations to model the nebula's formation, finding that its overlapping structure is an artifact of Earth's relative position — in reality, the material blown out from the collision is shaped not like a ring, but like two cones. Luckily, the Blue Ring Nebula is just the right age to reveal its origins: It was created when two stars collided and merged a mere few thousand years ago. If it were younger, the resulting single star (currently visible at the center of the nebula) would be hidden by the dust and debris. And if it were older, the nebula would simply look like a normal star, offering no clues to its origin. – ALISON KLESMAN

Voyage to the antipodes

Celestial opposites may be weirder than you think.



In a cosmic cause and effect, Mercury's Caloris Basin (left) and its jumbled, misshapen Weird Terrain are situated directly opposite each other on the tiny planet. NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/CARNEGIE INSTITUTION OF WASHINGTON; NASA/JPL/NORTHWESTERN UNIVERSITY



BY BOB BERMAN
Bob's newest book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

Before launching today's journey, the word *antipode* forces us to stroll along the old pronunciation footpath. That's a familiar trail, reached whenever a friend says things like "your-AIN-us." Granted, some celestial names are tough to decipher; you'd have to stop and grab a dictionary if you really want to pronounce Orion's left shoulder star correctly (it's bel-AY-trix, not bel-AH-trix).

Anyway, our subject is *antipode* and its plural, *antipodes* — words that indicate opposites and are challengingly pronounced AN-ti-pode and an-TIP-uh-deez. The British liked the concept enough that they often refer to the Australia and New Zealand region as the Antipodes because they're opposite England on the globe.

The search for antipodes uncovers surprising revelations.

Despite the unfortunate popularity of the Flat Earth movement, celestial objects are mostly spheres and, obviously, every location on each of those balls has a spot precisely opposite it — its antipode. Some of them demand our attention.

For example, Saturn's south pole is an unremarkable place with storms just like we see elsewhere in the solar system. But every 15 years, the opposite pole points in our direction and lets us have a look. Saturn's antipodal (an-TIP-uh-dal) extremities are a study in strangeness because its north pole — the one aimed our way this past decade — is surrounded by an enormous hexagon whose sides are each longer than Earth's diameter. Despite some unconvincing guesses, there's no plausible explanation for how nature could possibly create and preserve such an enormous geometric shape — especially when Saturn's antipode doesn't have one, despite similar temperatures, pressures, and winds.

But to truly explore antipodean weirdness, we can do no better than Mercury. The planet's largest feature is the Caloris Basin. This gargantuan circular impact feature resembles the greatest catastrophic places on the Moon, but what really catches our eye is the jumbled mess that lurks at its antipode. NASA's official name for this place: the Weird Terrain.

How would you like to write "the Weird Terrain" as your return address? What must have happened is debris and an unimaginable shock wave were thrown outward by the asteroid impact that created Caloris, which traveled supersonically in all directions until the wave collided with itself at the planet's antipodal point. There, the energy's violence either stirred up the Weird Terrain or else the physical material, having met itself, collapsed to the ground. Either way, it created a feature seen nowhere else in the universe. It remains an enduring monument to eeriness — so, hopefully in the future whenever the word *antipodal* arises in conversation (meaning never), the Caloris Basin and the Weird Terrain will immediately come to mind.

Antipodal phenomena inhabit the sky itself, even if relatively few people associate this aspect of nature with marvels ranging from the common and beautiful to the rare and subtle. Many lie precisely opposite the Sun alone: the twilight wedge, the rainbow, superior planets when brightest, the gegenschein, the lunar eclipse, and the glory.

With regard to constellations, antipodality sometimes played a central role in their folklore. One example is when Scorpius was supposedly placed opposite Orion so that, after the Hunter had been slain by the arachnid, the two enemies would never again lay eyes on the other.

A revelation I've never seen in print, but which I have uncovered by studying a star atlas, is that two of the five brightest stars, Canopus and Vega, are antipodal to each other on the celestial sphere. So, when pondering the fact that Vega will be the North Star 12,000 years from now and wondering what will then be the South Star, we have our answer. And what a spectacular situation — a magnitude 0 luminary near each of the poles!

We've seen enough to realize that the search for antipodes uncovers surprising revelations, making this a worthy enterprise when exploring the universe — the exact opposite of what we might have thought.

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

Titans of fire

Mars may have more than one rival.

CLOCKWISE FROM LEFT: Antares often rivals Mars (to its upper right) in color and brightness, as this image from September 26, 2014, shows. STEPHEN JAMES O'MEARA

These images of Mars were taken on the evening of September 3/4, 2020. They are intentionally out of focus to better reveal the planet's color. They show Mars when the planet was about 15° above the horizon (top) and five hours later, when it rose to 60°. STEPHEN JAMES O'MEARA

BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

I have long wondered why Antares (Alpha [α] Scorpii) gets to be the Rival of Mars — Ares is the Greek name for the Roman god Mars, so Antares ("Anti-Ares") is essentially named "Anti-Mars."

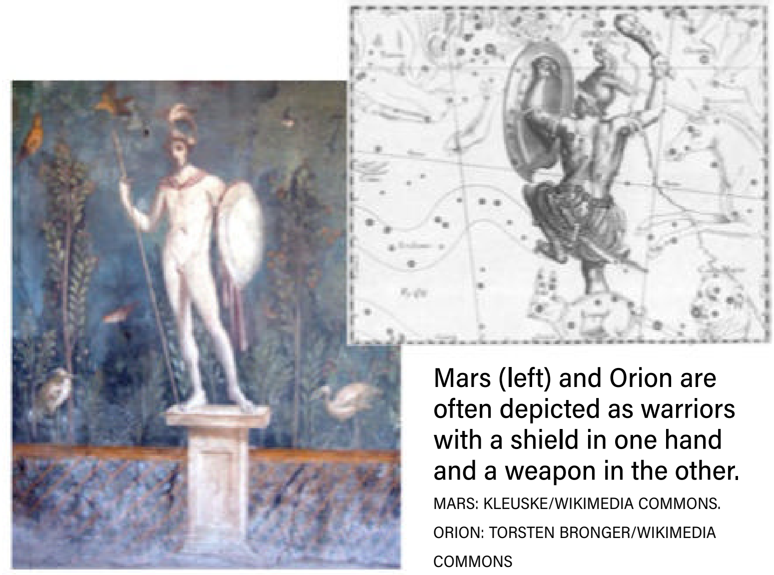
But the Red Planet also battles Betelgeuse (Alpha Orionis) and Aldebaran (Alpha Tauri) — both are of similar brightness and color. This month, you can see the fight for yourself as Mars marches off to war against these two titans at nightfall. The three scarlet sentinels all shine around 1st magnitude and are within about 35° of one another. When March opens, they form a line to the southeast. By midmonth, eastward-moving Mars will have bent that line into a shield. Then, by month's end, the three will morph into a spearhead, with Betelgeuse at the tip.

A chameleon planet

Mars is not always red. When high in the sky near opposition, Mars shines more golden yellow, like Arcturus or Saturn. And during favorable oppositions, the planet can outshine everything but Venus. At these times, Mars could hardly be considered a rival in color to any of the sky's reddish naked-eye stars.

In ancient times, the Romans gave these two states of Mars separate names. Golden Mars was Silvanus, an agricultural divinity who watched over the fields and guard crops. Red Mars was Gradivus, a warrior marching away from Earth to protect it in battle.

Given Mars' inconsistent appearance, I wondered if Antares had been singled out to be the planet's rival for some reason that had nothing to do with its similar color and brightness.



Mars (left) and Orion are often depicted as warriors with a shield in one hand and a weapon in the other. MARS: KLEUSKE/WIKIMEDIA COMMONS. ORION: TORSTEN BRONGER/WIKIMEDIA COMMONS

Early origins

So, what has Antares got that the other two reddish stars do not? The answer may be one of heritage and position. Consider the following:

• Ancient Babylonian skywatchers knew the god Mars as Nergal — god of war, pestilence, and death.

• The Greeks equated Nergal with their war god, Ares, whom the Romans later called Mars.

• According to the 1880 work *The Cyclopedia of Biblical, Theological, and Ecclesiastical Literature*, Nergal may also represent a deified version of Nimrod, the first king of Babylon and, according to the Old Testament, "a mighty hunter before the Lord" (Genesis 10:8).

• In his 1905 book *Myths and Marvels of Astronomy*, Richard A. Proctor tells us, "The giant Orion has long been identified with Nimrod."

So, if the god Mars is Nergal, and Nergal is the deified Nimrod, and Nimrod is Orion, then Mars is Orion.

In that case, the meaning of *Antares* — or Anti-Ares, aka the Rival of Mars — may instead refer to Antares as the Rival of Orion. We could equally say "Anti-Ares" means "opponent to Mars (aka Orion)" in the sense that the star is opposite Orion in the sky. That Antares, the alpha star of Scorpius, is a rival to both the alpha star of Orion and the planet Mars enhances the notion of these opposing forces.

These conjectures represent a vastly simplified version of the complex mythologies surrounding the origins of these ancient constellations. But further support may come from the myriad myths and legends surrounding the battles between Orion and the Scorpion and why they lie opposite one another in the sky.

One such link dates to ancient Egypt, where Orion represented as the sky god Horus in a boat. Mars, too, was depicted as Horus. In the sky, Horus lies opposite Osiris (the constellation we call Scorpius), the god of death and rebirth. When Horus rises, Osiris sets and slips into the underworld. The cycle represented how, in life, the pharaoh was Horus, while in death he became Osiris.

By the way, it just may be ironic that *Orion* is the spacecraft NASA plans to carry humans to Mars. As always, send your thoughts to sjomeara31@gmail.com.

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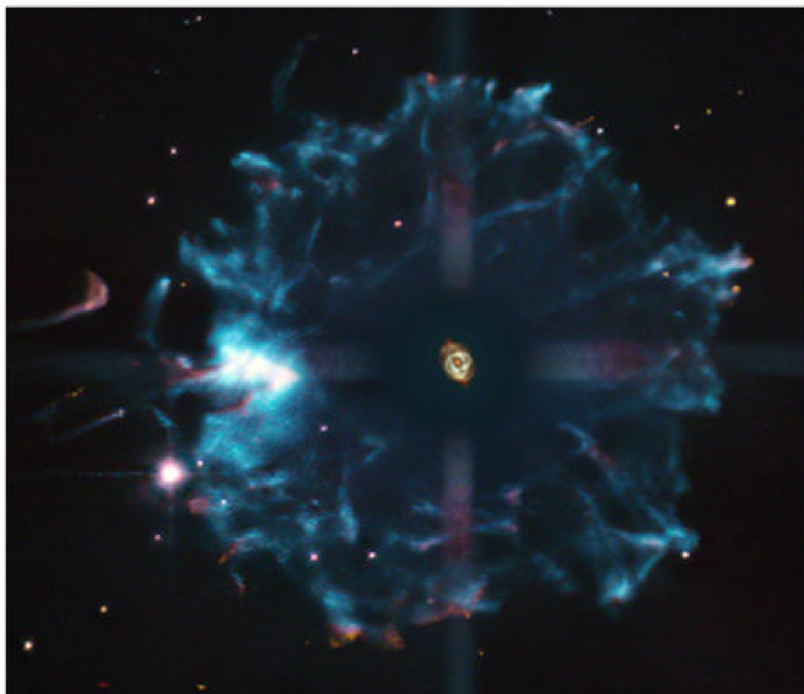
Backyard observing lists

Get the most out of your stargazing.



LEFT: The Cat's Eye Nebula is just one of many beautiful planetary nebulae included in the *Observer's Handbook*. OLEG BOUEVITCH

RIGHT: The 2021 *Observer's Handbook* lists a number of popular sets of targets, organized by season. PETER CERAVOLO/DEBRA CERAVOLO

BY GLENN CHAPLE

Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

I've always held the opinion that a backyard astronomer should never go outside without an organized list of objects to observe. Whether designed for a single evening or as part of a goal-oriented observing program, having a plan helps you avoid night after night of aimless searching, which could diminish your interest in the hobby. I offered ideas for one-night observing lists in my February 2020 column, "February's Finest Sights." But this time around, we'll look at some extensive compilations of deep-sky objects that can keep you engaged for nights on end.

Perhaps the best known deep-sky list is the Messier Catalog. And while it can serve as a single night list (if you're adventurous enough to tackle a Messier marathon), its 110 entries are better subdivided into a series of smaller lists that can be spaced out over the course of a year. The annual edition of the *Observer's Handbook*, published by the Royal Astronomical Society of Canada, includes a Messier Catalog list broken down by season. This month, the winter Messier objects are still visible after sunset. So, if you put four to six targets on each individual list (my recommended number for a single-evening session), you can view them all over the course of several nights.

The Messier Catalog isn't the only game in town.

However, the Messier Catalog isn't the only game in town. The *Observer's Handbook* has a matching 110-entry list of the finest NGC objects, again organized by season. Experienced amateur astronomers who own medium- to large-aperture scopes also will want to tackle the book's Deep-Sky Challenge, a 45-entry list arranged in order of increasing right ascension, put together by Alan Dyer and *Astronomy* contributor Alister Ling.

Want more? The *Observer's Handbook* also includes Deep-Sky Gems, a seasonal listing of 154 nebulae, clusters, and galaxies compiled by noted comet hunter David Levy. Finally, if you're a deep-sky specialist, you'll also find lists devoted to double and multiple stars, carbon stars, open and globular star clusters, and galaxies. The *Observer's Handbook* is an essential guide for amateur astronomers, filled with observing hints, a monthly sky calendar, and a wealth of data on solar system and deep-space objects. (The 2021 edition is available at MyScienceShop.com.)

For even more deep-sky lists, go to the website www.astroleague.com, scroll down to the menu on the left-hand side, and click on "Observing Programs." This page describes the Astronomical League's observing programs (featured in my March 2015 column, "Astronomical Game Plans"). From there, you can access an alphabetical list of the Astronomical League's 70-plus observing programs. Pick one that interests you and download the list. You don't have to be an Astronomical League member to do so, but if you are a member and complete a program, you're also eligible for a certificate and award pin.

Rich Kupfer of Boynton Beach, Florida, has created a deep-sky list of his own entitled "The Elite 800 (A Deep-Sky Catalogue for the Discerning Visual Observer)." Designed for the backyard astronomer equipped with a moderate telescope, it was compiled from thousands of observations Kupfer made over the course of 40 years. Arranged alphabetically by constellation, it lists some of the most notable multiple stars, variable stars, carbon stars, asterisms, and deep-sky objects. The entries for some constellations are short enough to place on a single-evening list. Others are rather extensive (Virgo's list covers nine pages!) and will need to be broken into multiple lists. Although "The Elite 800" was compiled with a 14-inch scope, many of Kupfer's entries are within reach of smaller-aperture instruments. Get your free PDF copy by contacting Kupfer at rkupfer3@comcast.net.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Which constellation has the most stars of spectral class K9?

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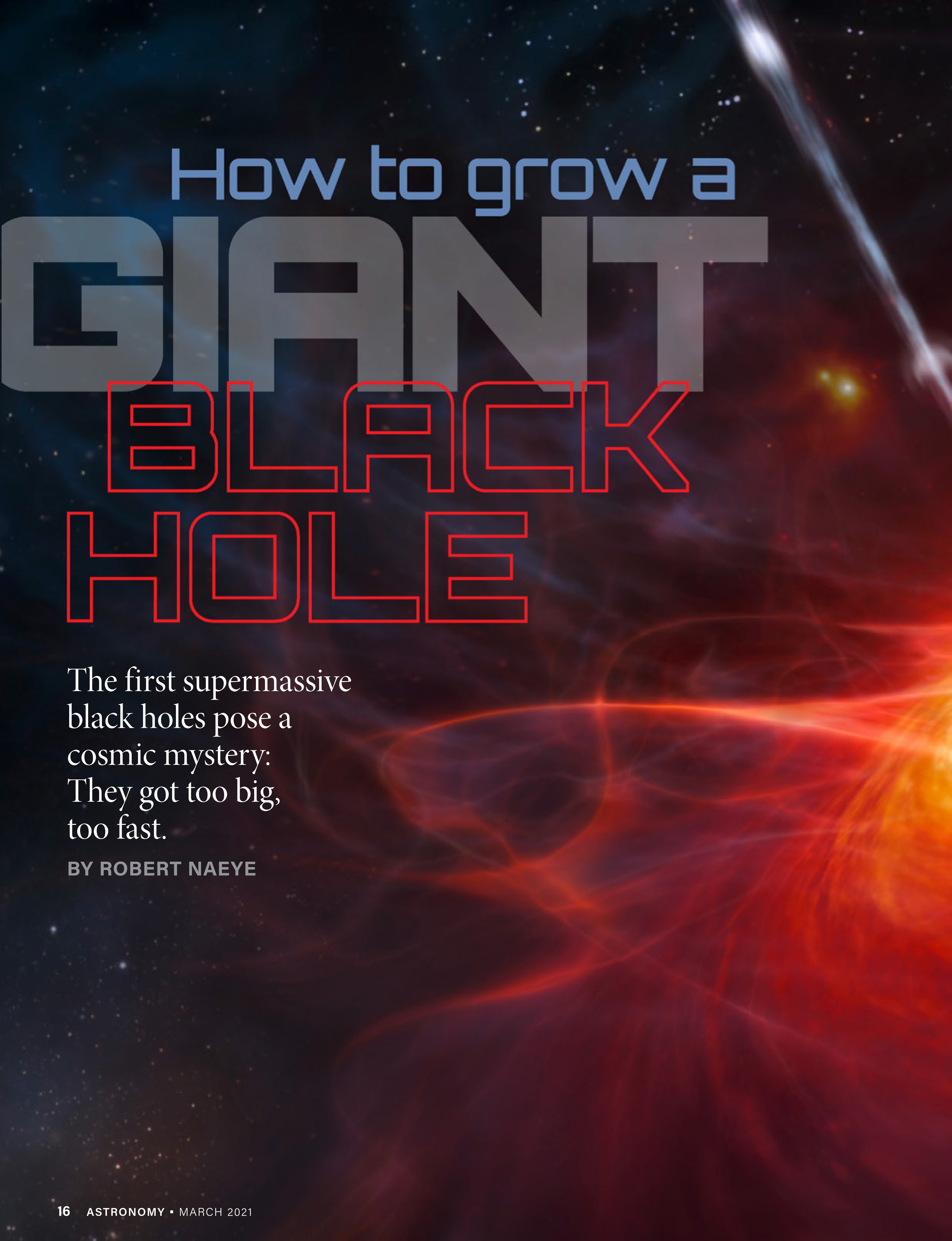


How to grow a GIANT BLACK HOLE

The first supermassive black holes pose a cosmic mystery: They got too big, too fast.

BY ROBERT NAEYE

IN 2017, astronomers started finding monster black holes in the very early universe. Containing roughly a billion times the mass of our Sun, these black holes were surrounded by disks of infalling matter shining so intensely that we can detect them across immense stretches of space and time.

These gravitational giants existed when the universe was only 700 million years old, or 5 percent its current age. At that point in cosmic history, the universe was still a toddler. Gravity was just beginning to rein in clouds of gas and dark matter to form structures that would later evolve into mature spiral and elliptical galaxies. Stars were beginning to pop into being, but they existed in far fewer numbers than they do today.

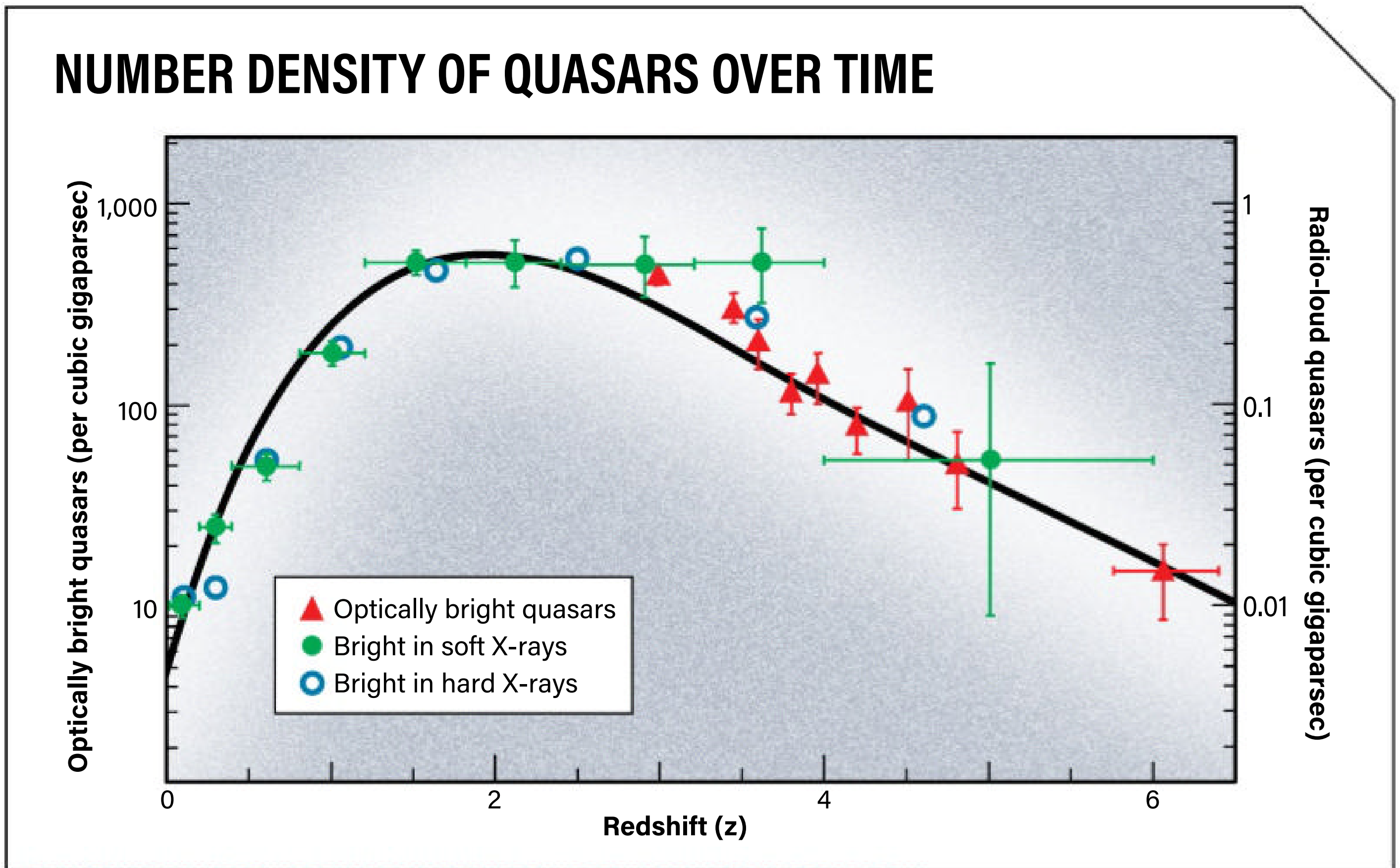
According to the traditional picture of black hole formation and growth, the universe at this time simply had not existed long enough for black holes to bulk up to a billion solar masses. So, based on our general understanding of how black holes form and grow, these black holes should not exist.

And yet they do — posing a major challenge that astrophysicists have yet to unravel.

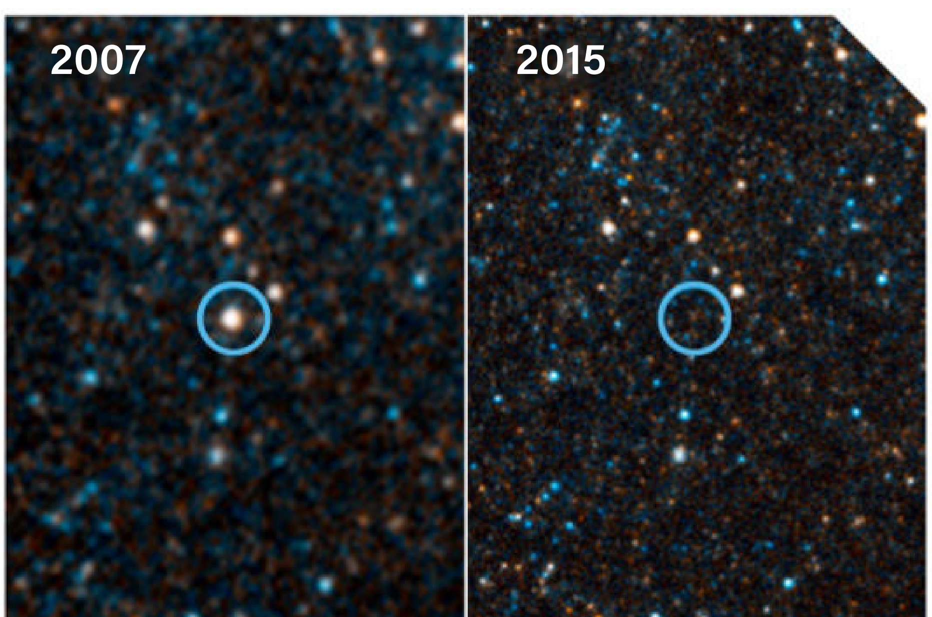
High-redshift quasars

Quasars are brightly shining beacons of light and energy generated by the accretion of material onto supermassive black holes. In the 1990s, astronomers using a combination of ground- and space-based telescopes started to find extremely distant quasars powered by black holes of a billion or more solar masses. By the mid-2010s, it was no longer a big deal to find quasars dating back to 1 billion or 2 billion years after the Big Bang. But theorists had a difficult time explaining how such massive black holes could have arisen so soon in the universe's history.

ULAS J1120+0641 is the first quasar discovered beyond a redshift of 7. Blazing at a time when the universe was just 770 million years old, ULAS J1120+0641 contains a supermassive black hole 2 billion times the mass of our Sun. Based on astronomers' current picture of how black holes grow, it is too massive for its age.
ESO/M. KORNMESSER



The number density of quasars decreases with increasing redshift, meaning there are fewer and fewer quasars scattered throughout space as astronomers look back in time to when the universe was younger. In this figure, the black line shows the number density of radio-loud quasars — quasars with powerful jets emitting at radio wavelengths — plotted by redshift. Also shown are the number densities of other types of quasars, such as those seen at optical (triangles) and X-ray (open and filled circles) wavelengths. Because there are only a few quasars at very early times, exotic explanations for how they grew so large so fast become more reasonable. *ASTRONOMY*: ROEN KELLY, AFTER J. WALL 2007



The most massive stars can directly collapse into black holes without first exploding as a supernova. For example, this pair of Hubble images shows a 25-solar-mass star (left) that simply "disappeared" without fanfare over time. Astronomers ultimately concluded it had likely collapsed directly into a black hole, dubbed N6946-BH1. NASA, ESA, AND C. KOCHANEK (OSU)

For quasars and other objects that existed many billions of years ago, it's meaningless to express their distances in terms of light-years. The universe has expanded so much between then and now that astronomers instead refer to an object's redshift, which is a measurement of how much cosmic expansion has stretched the object's light toward redder (longer) wavelengths.

For years, astronomers such as the University of Arizona's Xiaohui Fan have been identifying quasars at redshifts as high as 6, when the universe was about 900 million years old. They've even found a few around redshift 7, which corresponds to an era when the universe was about 735 million years old. But in late 2017, an international team led by Eduardo Bañados of the Carnegie Institution for Science announced a quasar at a record-shattering redshift of 7.54. This quasar, designated J1342+0928 (J1342 for short), based on its sky coordinates in Boötes, was radiating 40 trillion Suns' worth of energy at a time when the universe was only 690 million years old.

The team found J1342 by mining data from NASA's Wide-field Infrared Survey Explorer satellite, the United Kingdom Infrared Telescope Deep Sky Survey Large Area Survey, and the DECam Legacy Survey. They used the 6.5-meter Magellan Telescope in Chile to measure the quasar's redshift, while observations with the 8-meter Gemini North Telescope in Hawaii enabled the team to estimate the black hole's mass: around 800 million Suns.

"Gathering all this mass in under 690 million years is an enormous challenge for theories of supermassive black hole growth," said Bañados in the discovery announcement. "The finding shows that a process obviously existed in the early universe to make this monster. What that process is? Well, that will keep theorists very busy!"

Theorists had a difficult enough time accounting for the redshift-6 and redshift-7 quasars. But a supermassive black hole beyond redshift 7.5 borders on the absurd. And, as it turns out, the discovery was not a fluke.

In June 2020, a team with many of the same astronomers, this time led by Jinyi Yang of the University of Arizona, announced the discovery of a second quasar at a redshift greater than 7.5. This quasar, designated J1007+2115, lies at a redshift of 7.515. Its black hole engine weighs a whopping 1.5 billion solar masses at a time when the universe was barely 700 million years old.

Astronomers will likely find even more quasars beyond redshift 7.5 in the future. But probably not many. As Yang says, "The number density of quasars declines very rapidly with increasing redshift."

If quasars were common beyond redshift 7.5, then astronomers would have found several more by now. But their spatial density — the number of quasars in a given volume of space — appears to be very low, only about one quasar per cubic gigaparsec, where a gigaparsec is 3.26 billion light-years. "You have to survey huge areas of sky to

find these objects just because they are intrinsically so rare in the universe," says cosmologist Joseph Hennawi of the University of California, Santa Barbara. A member of the team that discovered both quasars, Hennawi also helped develop software that makes the discovery of high-redshift quasars more efficient.

That gives theorists some measure of relief. The relative dearth of high-redshift quasars means the conditions that form them are uncommon — i.e., a highly unusual set of conditions can do the trick, creating "seeds" that grow quickly into quasars. As University of Texas at Austin astrophysicist Volker Bromm says, "We only need very few seeds to explain the observed billion-solar-mass quasars at high redshift."

Still, that is easier said than done.

Slow going

According to the prevailing (and well-tested) cosmological model, known as Lambda-Cold Dark Matter (ΛCDM for short), the universe originated 13.8 billion years ago in the Big Bang. The early universe was initially a nearly featureless cauldron of subatomic particles and dark matter (which outweighs familiar atomic matter by nearly 6 to 1), with material almost evenly distributed and thus unable to clump together into interesting structures.

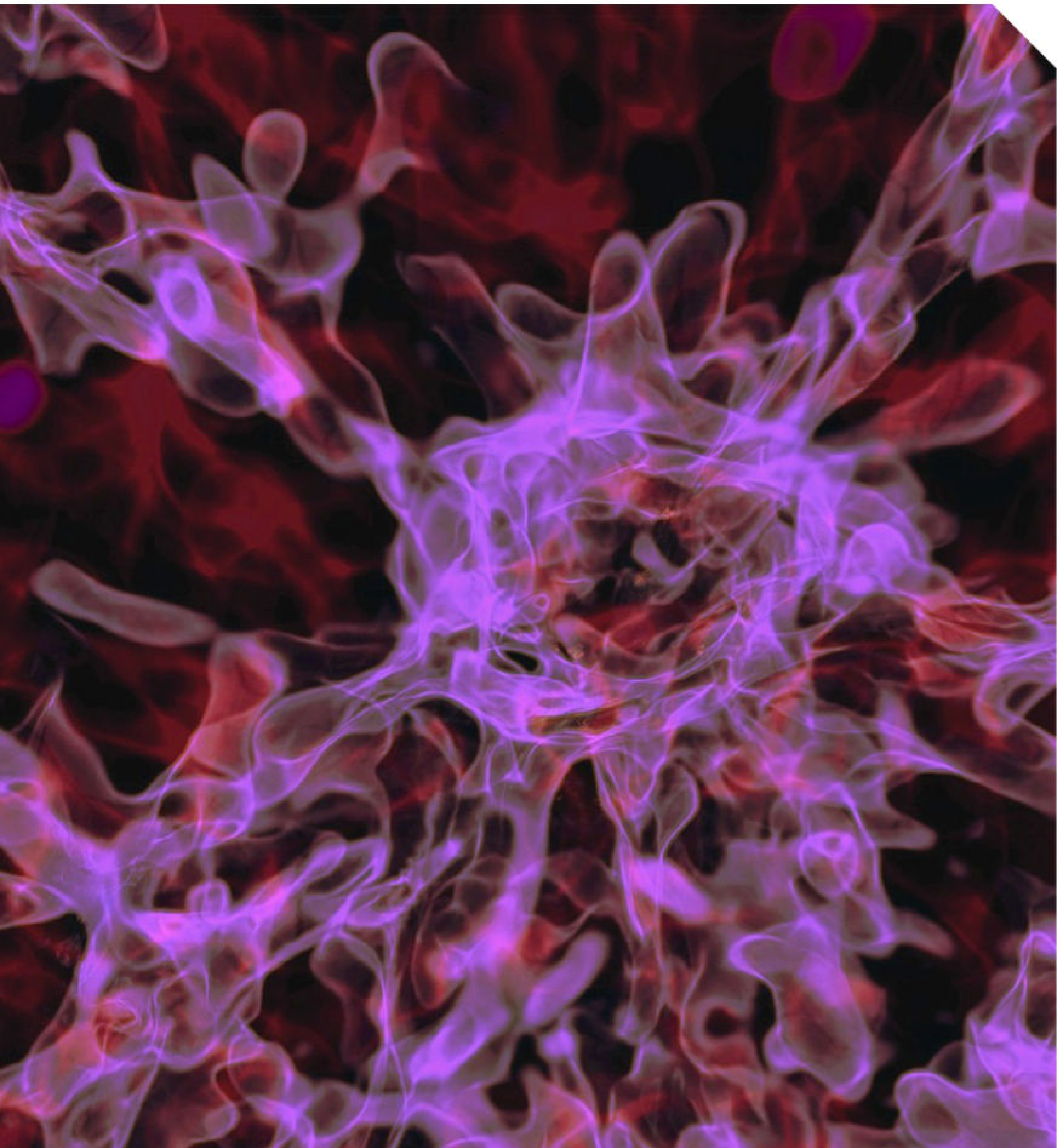
Crucially, in the first few minutes of the universe's existence, the prevailing temperatures and pressures enabled subatomic particles to coalesce into hydrogen and helium nuclei, with only the barest traces of heavier elements. When the universe cooled further, 380,000 years later, electrons combined with the hydrogen and helium nuclei, forming neutral atoms and releasing the cosmic microwave background radiation (CMB).

"We only need very few seeds to explain the observed billion-solar-mass quasars at high redshift."

High-resolution measurements of the CMB show that the universe at this time was extremely — but not perfectly — uniform. Subtle irregularities in the density of matter eventually enabled gravity to do its thing. Starting around 200 million years after the Big Bang, regions with slightly greater concentrations of dark matter and gas started collapsing into the first stars and protogalaxies.

But this early era of cosmic history remains out of reach for observers. So to investigate it, theorists perform sophisticated computer simulations, which help tease out what happened as pristine clouds of hydrogen and helium gas gravitationally collapsed. According to calculations, these clouds fragmented into multiple clumps that formed stars with masses up to 500 Suns. These early beacons lived fast and died young,

With a redshift of 6.6, CR7 (depicted in this artist's concept) is a distant galaxy shining with stars just 800 million years after the Big Bang. Nearby is a bright patch of gas that appears devoid of stars. Juxtapositions like this could be the precursors of direct-collapse black holes. ESO/M. KORNMESSER



Supercomputer simulations allow researchers to study how gas in the early universe might collapse directly into black holes. As the gas flows inward, it streams along filaments of dark matter called the cosmic web, congregating in areas of higher density that will later form galaxy groups and clusters. AARON SMITH/TACC/UT-AUSTIN

shining with millions of times the energy of our Sun but lasting only a few million years. They died in stupendous supernova explosions, and their cores collapsed into black holes with 100 to 200 solar masses.

These black holes then started devouring nearby material, each like a Pac-Man gone berserk, occasionally even gobbling up entire stars. They probably even merged with one another to form black holes with many hundreds, or perhaps several thousand, of solar masses.

But even the most ravenous black hole could not consume enough material in 500 million years to attain the mass of a billion Suns. That's because as matter gathers around a black hole, it settles into an accretion disk. Whizzing around the black hole at near-light-speed, the disk heats up and blasts out torrents of radiation across many wavelengths. This intense radiation exerts pressure that literally pushes away nearby matter, limiting how fast the black hole can add mass. An object's theoretical maximum accretion rate is known as the Eddington limit, after British astrophysicist Sir Arthur Eddington (1882–1944).

Even if a black hole can pull in matter faster than the Eddington limit, that increased accretion should produce powerful winds and outflows that drive material away, choking off further growth. In other words, if episodes of super-Eddington accretion do occur, they are presumably brief in duration, setting yet another limit on how fast a black hole can grow.

Because of these natural limits, astronomers find it difficult to explain how a black hole starting off with 100 to 200 solar masses can accrete enough material in only a few hundred million years to grow into the billion-solar-mass behemoths powering the quasars J1342 and J1007. For that, we need to seed black holes with much higher initial masses. But how are they born?

Direct collapse

It turns out, a model dating back more than a decade offers a potential solution.

In 2006 and 2007, Yale University astrophysicist Priyamvada Natarajan, working with Giuseppe Lodato (now at the University of Milan in Italy), published a series of papers explaining how dense primordial gas clouds (essentially protogalaxies) in the early universe could have collapsed to form seed black holes with masses of 1,000 to 100,000 Suns. Normally, such clouds would have fragmented during the collapse process to form a multitude of massive stars instead of a single black hole. But under certain rare conditions, a few clouds could have collapsed to form extremely massive black holes.

The key to this process is how gas clouds cool. Most of these clouds in the early universe contained a high abundance of molecular hydrogen (H_2), which consists of two hydrogen atoms bound together. Natarajan and Lodato found that such clouds

will cool quickly, which causes them to fragment into numerous clumps that will each go on to form a star.

But if a small primordial cloud lies close to a much larger protogalaxy that is rapidly forming stars, those stars relentlessly zap the cloud with ultraviolet radiation. This massive input of energy breaks the chemical bonds that bind molecular hydrogen together, converting the cloud into one of almost pure atomic hydrogen (H), which is less efficient at radiating away energy. This gas remains hot, meaning it can't fragment into clumps that cool and condense to form stars.

Instead, the cloud gravitationally collapses without cooling, ultimately concentrating such a huge amount of mass into such a small volume of space that it forms what Natarajan calls a "direct-collapse black hole," or DCBH. This process bypasses the formation of traditional stars, although it could form a very short-lived supermassive star.

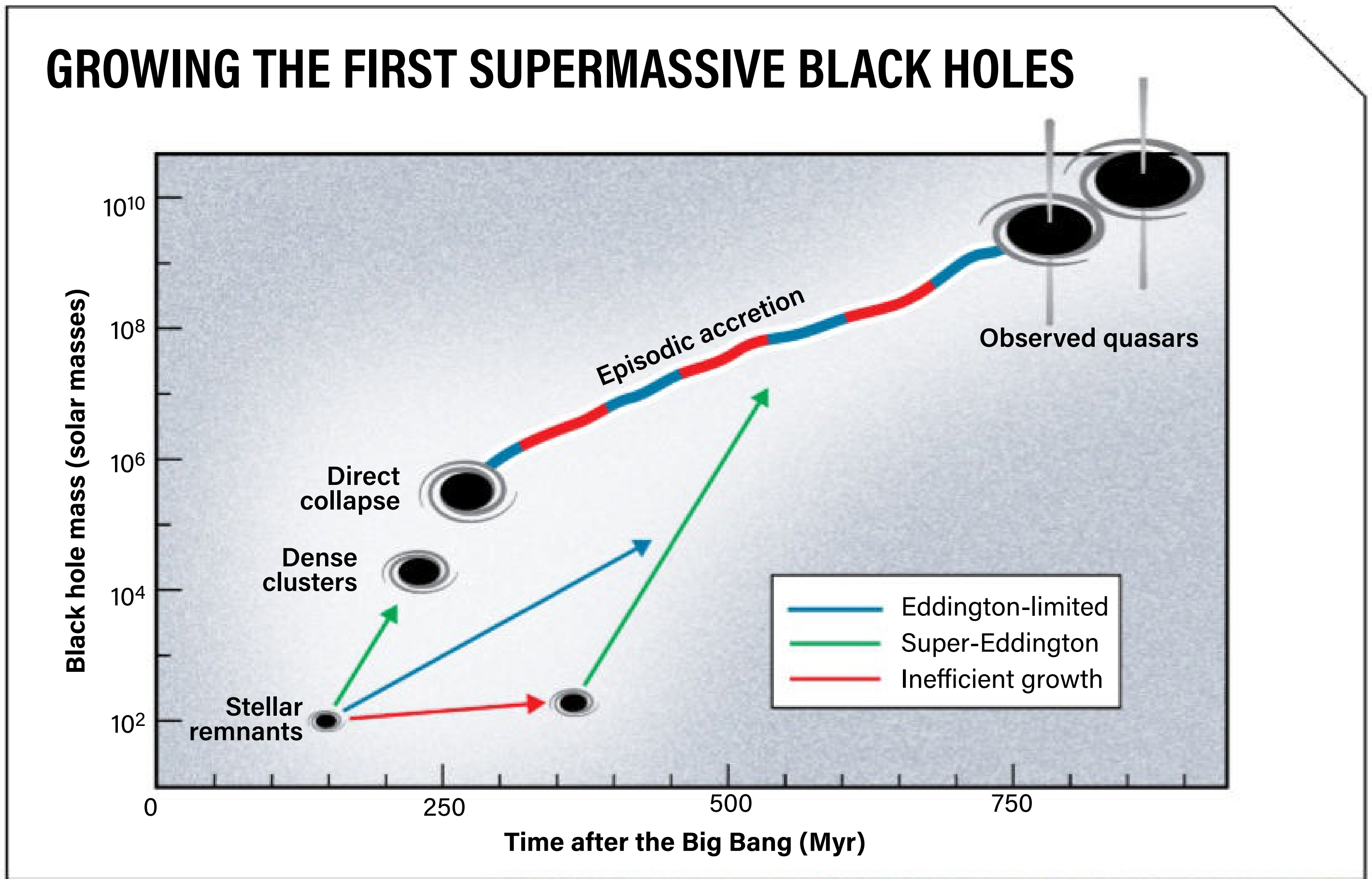
Natarajan's simulations show that the DCBHs could have formed with as much as a million solar masses. Such a massive black hole would have quickly merged with the nearby galaxy, where it could have bulked up very rapidly on stars and gas. Natarajan and Lodato originally intended this model to explain ultra-massive black holes — those with masses of 1 billion Suns or more — at slightly lower redshifts. But it also offers a promising solution to the timing problem for the redshift-7.5 quasars by creating seeds massive enough to quickly grow into quasars in a short time.

Natarajan emphasizes that "special conditions" are required to form these DCBHs: a small primordial cloud of hydrogen and helium gas sitting at just the right distance to a much larger star-forming galaxy. This explains why high-redshift quasars are uncommon. "The conditions that you need are pretty stringent to make direct-collapse black holes," she says. "Those conditions are rare in the early universe, but they are available. Luckily, these monster black holes are very rare, so you can accommodate what is seen so far, easily, without a problem."

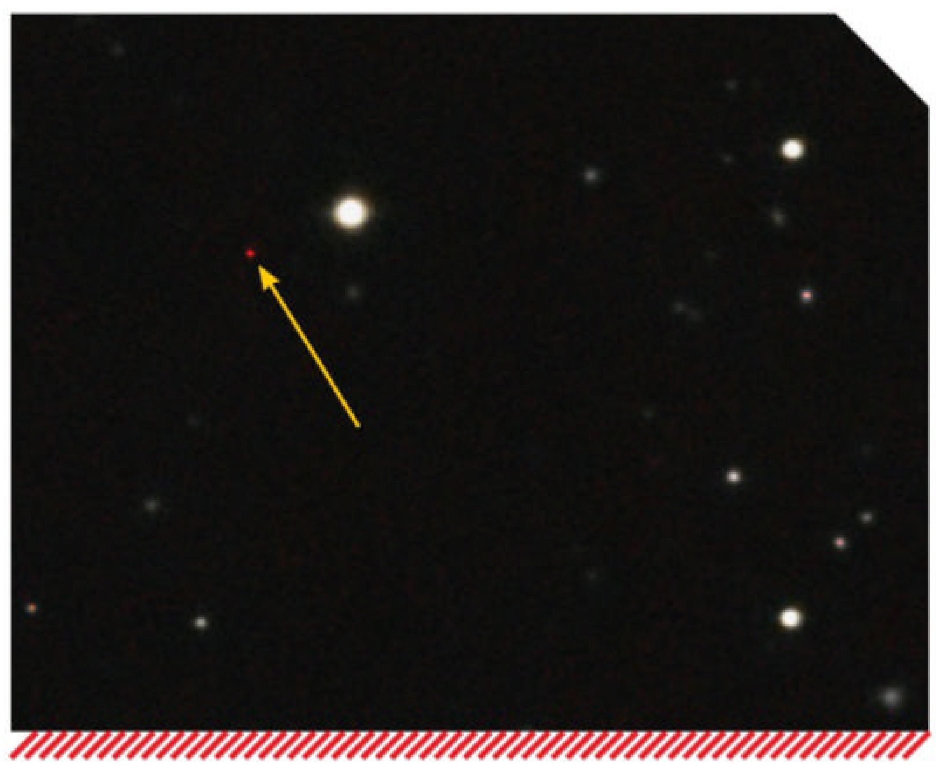
The DCBH model seems to work in a computer simulation. But did such black holes actually form in the real universe?

We shall soon find out. Natarajan says her model can be directly tested in the near future. Even the supermassive black holes that power quasars contain only a few percent of their host galaxy's total mass. But a DCBH would outweigh the total mass of stars in its small host galaxy by up to 50 times, Natarajan says, creating a bizarre object known as an obese black hole galaxy. (For comparison, the SMBHs at the centers of galaxies in the local universe typically have only 1/1,000 the mass of the galaxy's stars.) Obese black hole galaxies would be relatively bright at infrared wavelengths, with a characteristic spectrum. "They have a unique signature, so we aren't going to be confounded with any other kind of peculiar galaxy or object," she says.

NASA's James Webb Space Telescope (JWST), currently scheduled to launch in late 2021, should be able to detect DCBHs at redshifts 9 to 12 (when the universe was about



How do you make billion-solar-mass quasars early in the universe? The seeds of these monster black holes, which can come from sources such as the deaths of massive stars or direct-collapse black holes, may have undergone periods of intense (super-Eddington) growth, interspersed by times of limited (Eddington-limited) or inefficient growth. *ASTRONOMY*: ROEN KELLY, AFTER SMITH & BROMM, 2019



The quasar ULAS J1120+0641 appears as the small red point of light in this composite image, which combines data from the Sloan Digital Sky Survey and the UKIRT Infrared Deep Sky Survey. ESO/UKIDSS/SDSS

526 million to 354 million years old, respectively). And whether it detects these objects will test their model, Natarajan says. "If you grow the black hole from a tinier seed by redshift 9, it would be too faint to be picked up by JWST. So, if the JWST sees any quasar between redshift 9 and 12 … it has to have been a DCBH. We'll put our neck out there and make that prediction."

Many mergers

Theorists have come up with other ideas about how the universe could birth the massive seeds of supermassive black holes. A March 2020 paper in *The Astrophysical Journal* by Lumen Boco, Andrea Lapi, and Luigi Danese of Scuola Internazionale Superiore di Studi Avanzati (International School for Advanced Studies) in Trieste, Italy, mathematically shows how numerous individual black holes formed from massive stars inside a young galaxy can combine to create a SMBH seed.

First, massive stars live out their life cycles, creating many smaller black holes. As these black holes plow through the dense gas within their host galaxy, it creates dynamical friction, or drag, that causes them to rapidly migrate toward the galaxy's center. There, they can merge to form a single black hole with 10,000 to 100,000 solar masses. This process progresses extremely quickly, taking just 50 million to 100 million years. After that, the researchers said in a press release, the central black hole will grow quickly: "In light of this theory, we can state that 800 million years after the Big Bang, supermassive black holes could already populate the cosmos."

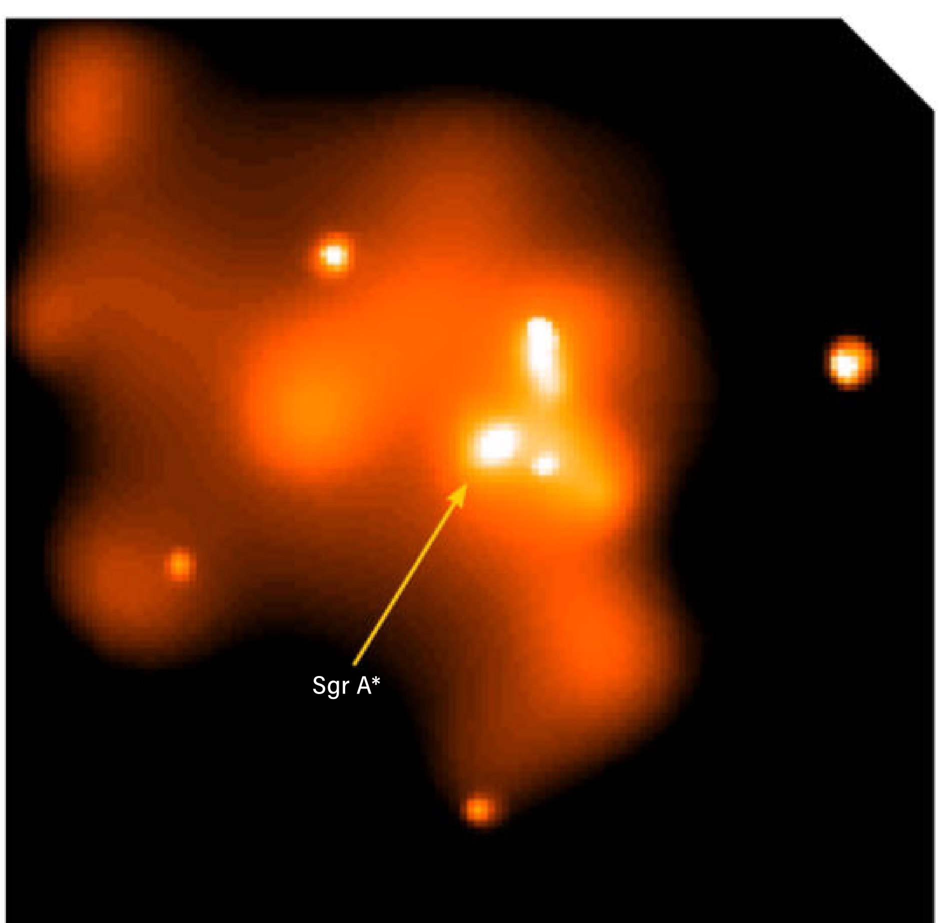
"The conditions that you need are pretty stringent to make direct-collapse black holes. Luckily, these monster black holes are very rare, so you can accommodate what is seen so far, easily, without a problem."

Boco, Lapi, and Danese note that gravitational-wave detectors such as LIGO/Virgo and the European Space Agency's upcoming Laser Interferometer Space Antenna mission could detect the rumbles of these ancient mergers.

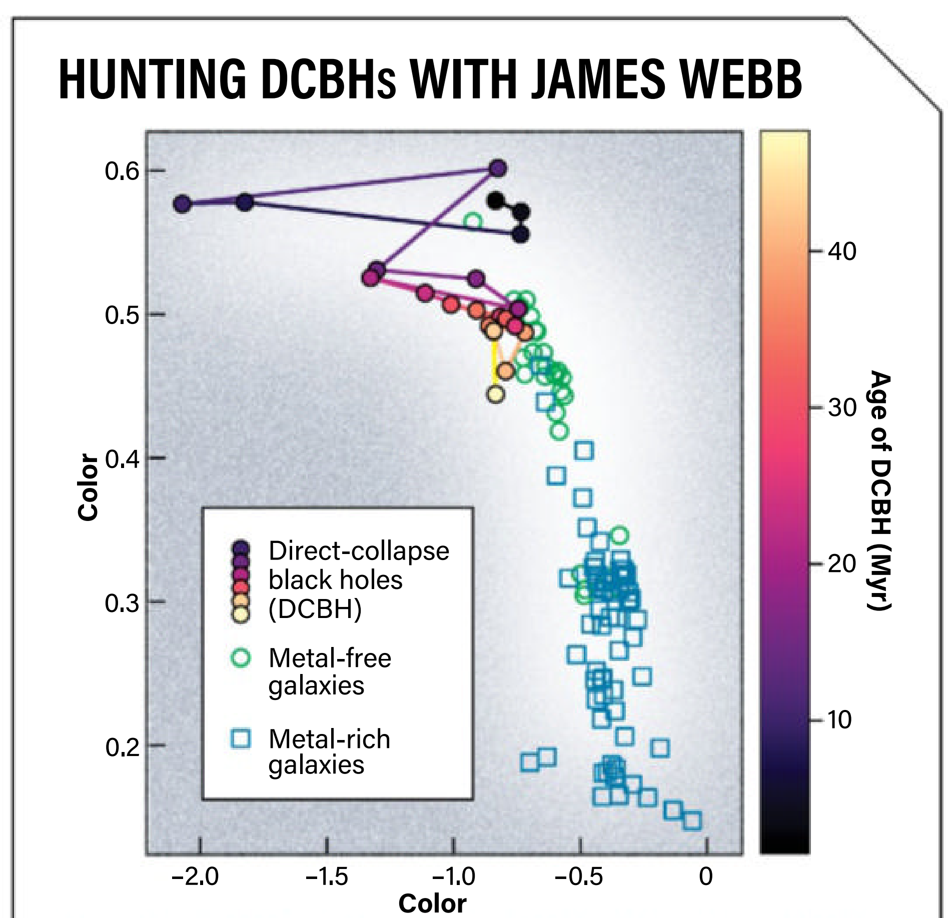
Going super-Eddington

But there's yet another way around the growth problem. What if some black holes in the early universe were able to accrete matter at super-Eddington rates for prolonged periods of time? In this scenario, a black hole starting off with a few hundred solar masses could have bulked up relatively quickly into a billion-solar-mass behemoth.

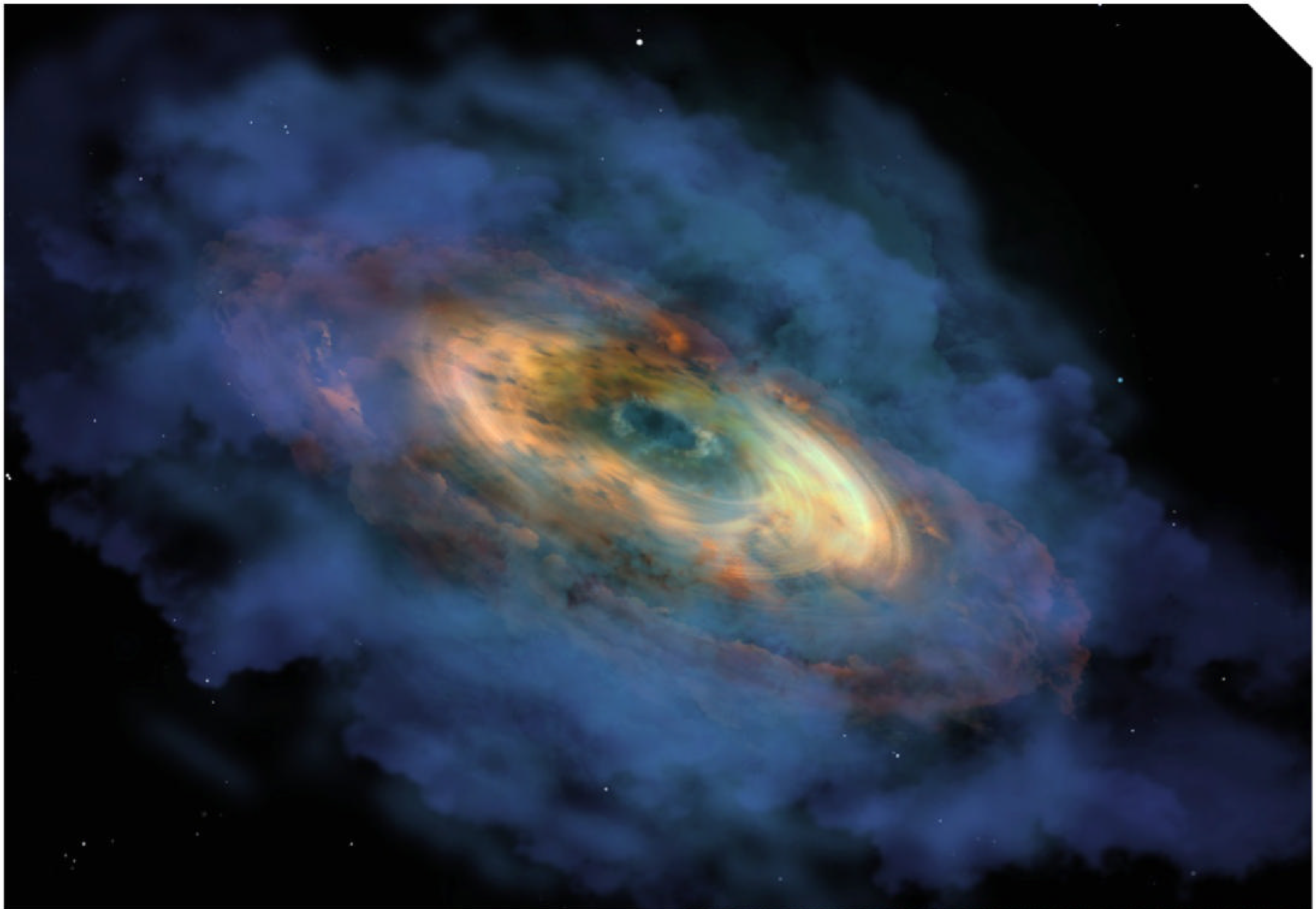
Hennawi, his Santa Barbara colleague Frederick Davies, and other collaborators have recently performed observations suggesting this



Half of the 2020 Nobel Prize in Physics went to researchers Andrea Ghez and Reinhard Genzel for their discovery of the supermassive black hole at the center of the Milky Way. Called Sagittarius A* (Sgr A*) and pictured here in X-rays from the Chandra X-ray Observatory, this monster black hole weighs more than 4 million times the mass of our Sun. Astronomers think Sgr A* — and all SMBHs — grew as quasars. The challenge is uncovering how quasars 1,000 times more massive than Sgr A* formed so quickly in the early universe. NASA/MIT/PSU



In observations taken by the future James Webb Space Telescope, astronomers expect direct-collapse black holes (DCBHs) to look very different from other objects in the early universe. For example, this figure shows the expected colors — obtained by subtracting the amount of light an object gives off in different filters — of various sources in JWST images, including DCBHs (filled circles) and early galaxies (open circles and squares) with different types of stars. ASTRONOMY: ROEN KELLY, AFTER BARROW, ET AL., 2018



This artist's concept depicts the 10,000-solar-mass seed black hole that would grow to produce the distant quasar J1007+2115 (also called Pōniuāʻena). The seed, shown when the universe was 100 million years old, is surrounded by an accretion disk (yellow-orange) and, farther out, a cloud of gas (blue) on which it can chow down. INTERNATIONAL GEMINI OBSERVATORY/NOIRLAB/NSF/AURA/P. MARENFELD

might have been the case. Using the Magellan and Gemini telescopes, they have measured the amount of light from several redshift-7 quasars by observing how their radiation has ionized the intergalactic gas between the quasar and us.

"We came to the conclusion that the standard picture of black hole growth may actually not apply to these quasars," says Hennawi. "They're eating a lot of material but they're not emitting nearly as much radiation as we thought. They grow so fast that there's no longer a black hole growth problem."

Theorists have a difficult time simulating how black holes accrete material. The underlying physics is exceedingly complex, especially for supermassive black holes. But one thing is clear: The presence or absence of magnetic fields, and how they arrange themselves around a black hole, plays a critical role in controlling the rate of the accretion flow.

Magnetic fields thus determine how efficiently a gram of matter radiates light as it spirals toward a black hole. A magnetic field with twists and turns will gum up the flow, causing it to heat up and emit powerful radiation that could stem the infall of material. But, says Natarajan, if the magnetic field takes a direct path and neatly threads an accretion disk, simulations suggest it can whisk material to the black hole, feeding it much faster than the Eddington rate.

If either the direct-collapse or super-Eddington scenario is correct, there is no need to tinker with the ΛCDM cosmological model. And Hennawi points out that it's not necessarily an either/or proposition. Both direct collapse *and* super-Eddington accretion could have been operating in the early universe, he says. Natarajan agrees.

Like Natarajan, Hennawi looks forward to the launch and deployment of JWST. Assuming it works as planned, this cutting-edge space telescope will enable astronomers to make measurements of many dozens of high-redshift quasars to see how the energy they produce is affected by the rate at which they accrete material.

"At some level the abundance of ideas is what you really want and need, but the important thing is that we'll have a lot more understanding of this when we can make these kinds of measurements for a hundred objects," Hennawi concludes. "That's really what JWST will allow us to do."

Former Astronomy *senior editor* **Robert Naeye** *is a freelance writer based near Hershey, Pennsylvania. Visit his website at www.robertnaeye.com.*

MISSION TO THE CENTAURS

Planetary scientists are planning a blockbuster mission to an exotic world that's escaped from the Kuiper Belt. **BY S. ALAN STERN**

22 October 2038:

After a journey of over a billion miles to the outer solar system, the Centaurus spacecraft is on final approach. Dead ahead lies Chiron, a mini-planet orbiting between Uranus and Saturn.

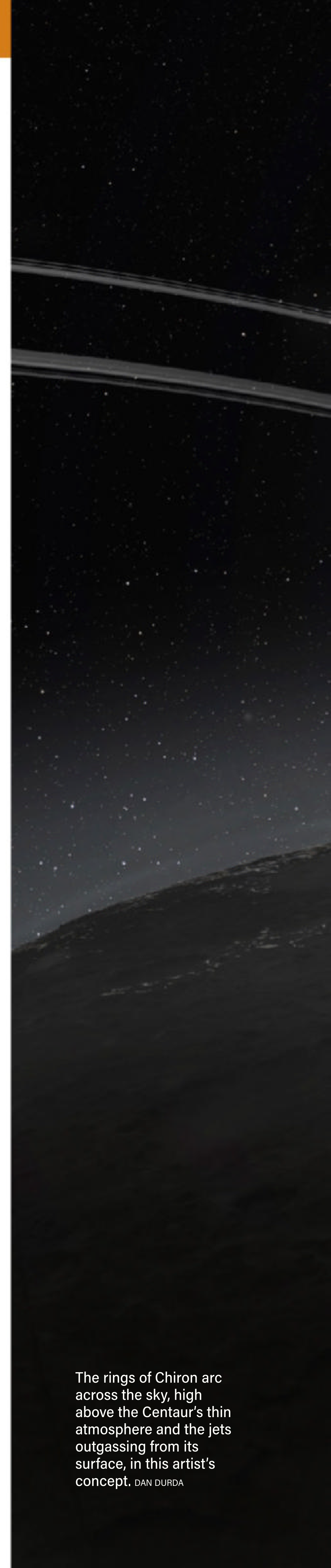
A native of the Kuiper Belt formed over 4 billion years ago, Chiron was recently (at least in astronomical terms) gravitationally dislodged from there and tossed into its current closer climes. Exploring it is now much easier than if it were still in the Kuiper Belt, over three times farther away.

And what a scientifically mouthwatering prize Chiron is. Known to have rings, an atmosphere, and surface activity, Chiron is also a world that lies in the critical size gap between planetesimals (the formation seeds of planets) and full-fledged planets, like Pluto.

A United Launch Alliance Atlas V rocket — pictured here lifting off from Cape Canaveral on August 5, 2011 — could send Centaurus on its journey. UNITED LAUNCH ALLIANCE

Centaurus crossed that billion miles from Earth to Chiron to make the first reconnaissance of this amazing outer solar system world. Once all the precious images and spectra are collected to turn Chiron from a point of light into a real place, Centaurus will transmit them back to its international science team, the most diverse ever assembled for any solar system mission.

What lies ahead for Centaurus on final approach to Chiron? Raw exploration, fundamental discoveries, and the honor of being the first to visit the last large unexplored population of bodies this side of the Oort Cloud: the Centaurs, of which Chiron was the first discovered and is the best known.



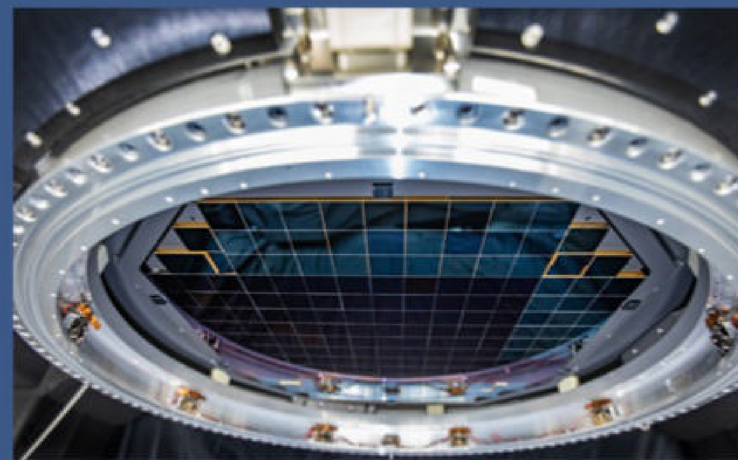
The rings of Chiron arc across the sky, high above the Centaur's thin atmosphere and the jets outgassing from its surface, in this artist's concept. DAN DURDA

SKY SCANNER

One of the most highly anticipated astronomical facilities of this century is the Vera C. Rubin Observatory (VRO).

This National Science Foundation project (with contributions by the U.S. Department of Energy and private donors like the Simonyi Foundation) is, at its heart, a giant 8.4-meter patrol telescope. When it comes online in 2023, it will repeatedly scan the skies every night and automatically analyze its images for any differences — objects that newly appear, change in brightness, or move in unexpected ways. This ability will make dramatic scientific contributions to studies of everything from novae and supernovae to dark matter and gamma-ray bursts.

VRO will also advance knowledge of our own solar system, multiplying the number of known asteroids, comets, and Kuiper Belt objects many times over. And it will catapult the currently known population of Centaurs from a few hundred to many thousands — perhaps even 10,000 — by the mid-2020s. This will in turn offer Centaurus more flyby targets to visit, further increasing the impetus to get it funded and flying. *— S.A.S.*



TOP: Vera C. Rubin Observatory's detector will be the largest digital camera in the world, with a total of 189 sensors and a resolution of 3,200 megapixels. JACQUELINE ORRELL/SLAC NATIONAL ACCELERATOR LABORATORY

BOTTOM: The camera was built by SLAC National Accelerator Laboratory in Menlo Park, California, and completed in January 2020. JACQUELINE ORRELL/SLAC NATIONAL ACCELERATOR LABORATORY

Meet the Centaurs

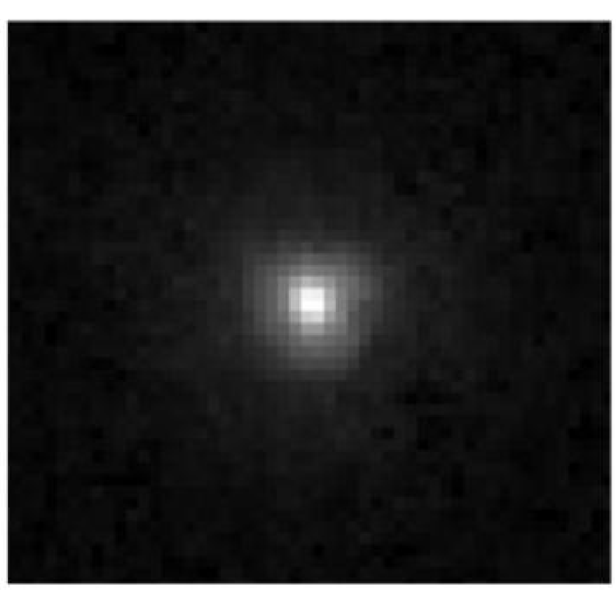
When Clyde Tombaugh of Lowell Observatory detected Pluto in 1930, it was thought to be a lonely body orbiting in an empty region beyond Neptune. But with the discovery of the Kuiper Belt in the 1990s, it became clear that Pluto had in fact been a harbinger of the vast population of planets and planetesimals orbiting in this region.

However, a strong clue to the existence of the Kuiper Belt came nearly 15 years before the first Kuiper Belt object (KBO) discovery in 1992. That clue was the discovery of an object named Chiron in 1977 by American astronomer Charlie Kowal of the Carnegie Institution.

When Kowal first spotted Chiron, it was initially designated as an asteroid with the number 2060. But Chiron quickly became an enigma because nothing like it had ever been seen — a solid body over a hundred miles (161 kilometers) across, orbiting not within the asteroid belt beyond Mars, but among the giant planets. Some thought it was the core of a giant comet. Others conjectured it was an asteroid that had escaped from the main belt.

It soon became clear that Chiron was neither. Instead, it became the first known member of a new class of solar system bodies named Centaurs, which mostly orbit between Jupiter and Neptune.

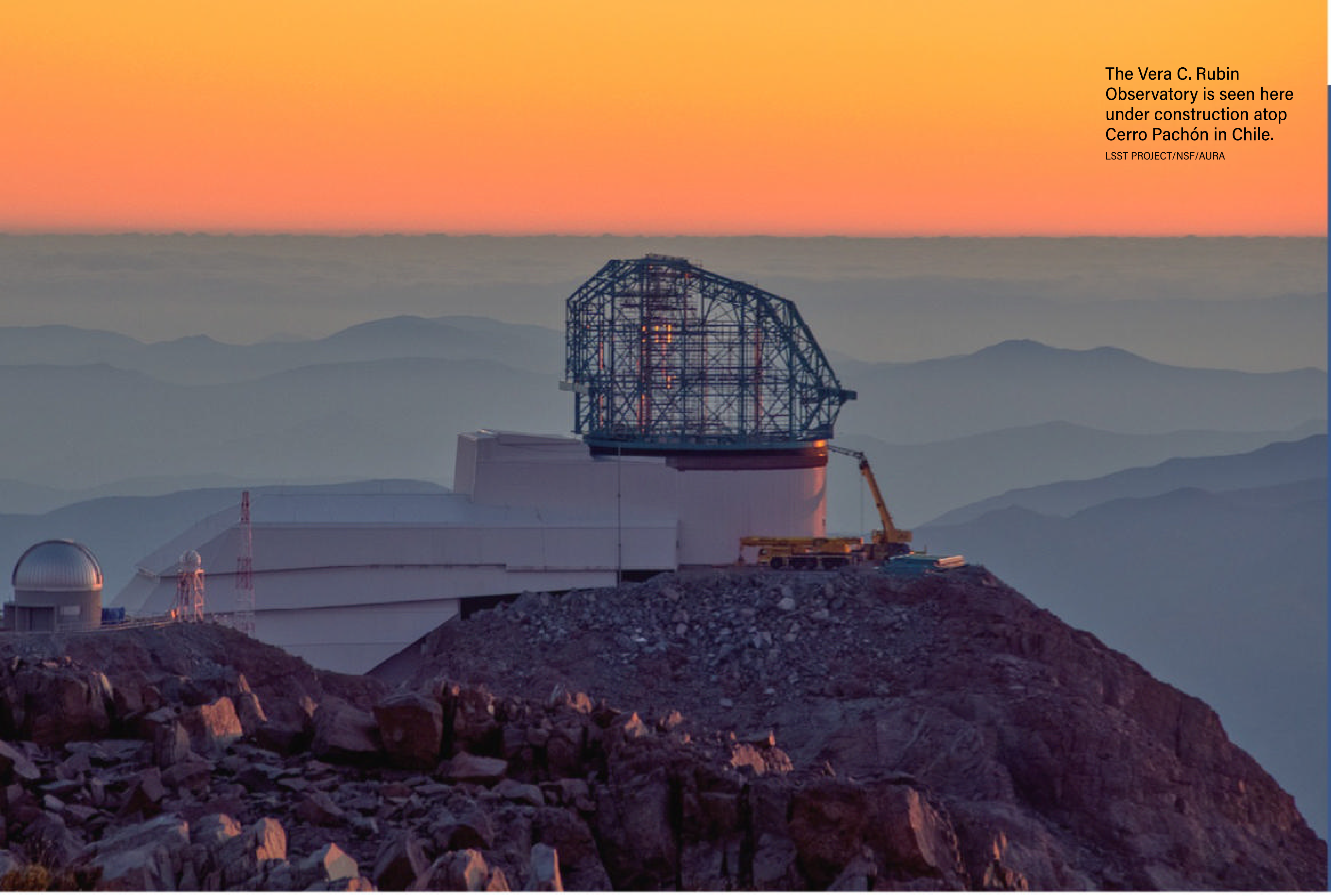
Today we know of hundreds of Centaurs, and we know their provenance:



Chiron is little more than a point of light from Earth, even in this Hubble Space Telescope image. HUBBLE SPACE TELESCOPE/KAREN MEECH

They are a population of recently dislodged KBOs that must be constantly resupplied from the Kuiper Belt. Why the need to be resupplied? Because the orbits of Centaurs cannot persist for long — the strong gravitational tugs of the giant planets disturb their orbits, eventually setting them either on a collision course to impact one of the planets or on an escape path ejecting them from the solar system entirely. Thus, they're lost from the Centaur population within a few million years — an astronomical blink of an eye.

Because these Kuiper Belt refugees lie so much closer to Earth than to the Kuiper Belt itself, they are brighter and bigger in our telescopes and therefore easier to study. In recent decades, we have learned that the Centaurs are a surprisingly diverse population, with members ranging from merely miles across to the sizes of Chiron and Chariklo, the two biggest Centaurs, with diameters of 137 and 205 miles (220 and 330 km), respectively. A handful of them, including Chiron, are active,



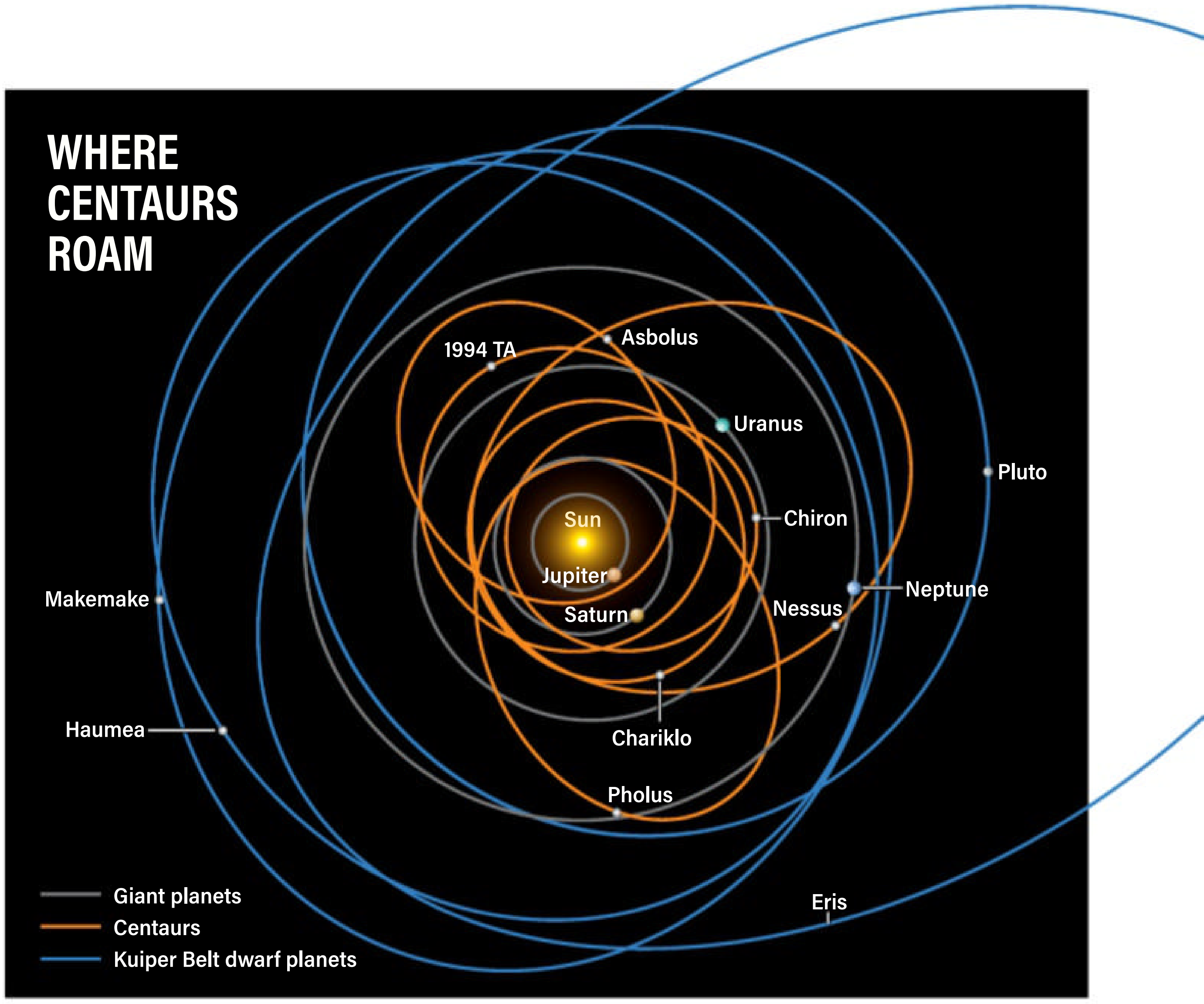
The Vera C. Rubin Observatory is seen here under construction atop Cerro Pachón in Chile.
LSST PROJECT/NSF/AURA

sporting comae — fuzzy, cometlike atmospheres — and even what appear to be discrete jets of gas and dust. Their surfaces display a range of colors, from neutral gray to extremely red, and their surface compositions vary as well, from water ice to organic compounds. A few have moons and some, including Chiron and Chariklo, even have rings.

A scientific wonderland

The Centaurs are so scientifically important that both of the past two Planetary Decadal Surveys of the U.S. National Academy of Sciences have pointed to the need to explore them. The mission of Centaurus is therefore to do just that, and Chiron is on our itinerary as a prime target.

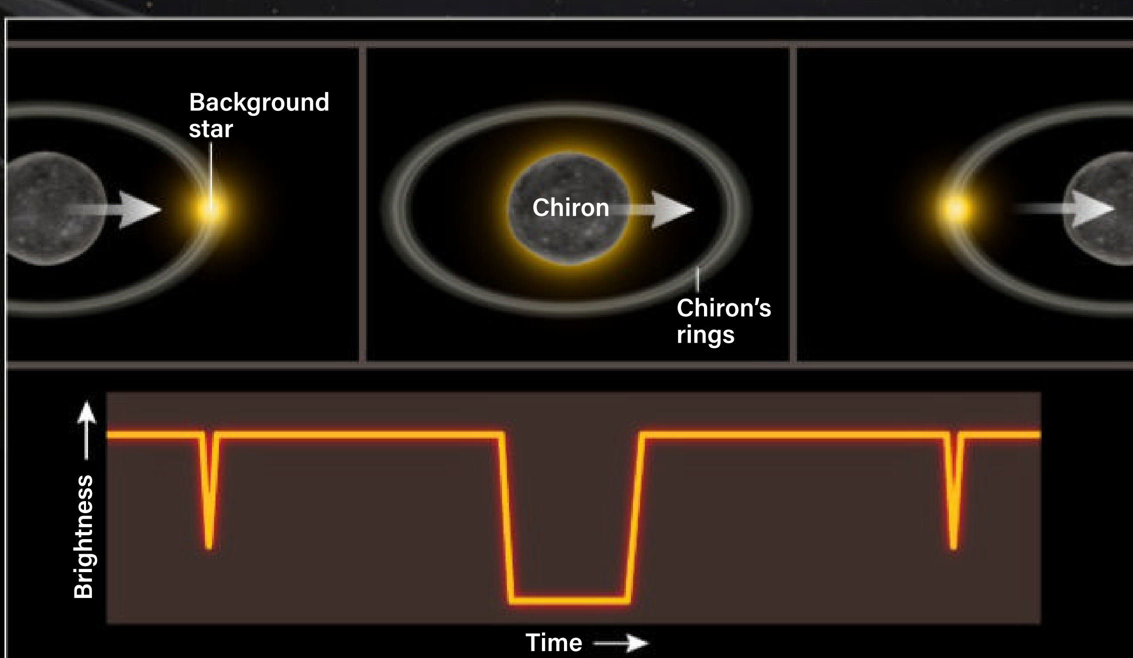
Beyond its notoriety as the first discovered Centaur and the second-largest body known in that population, Chiron can also be called triply blessed, scientifically. Why? Because it possesses all three of the most interesting characteristics of the known Centaurs: an atmosphere, surface activity, and what appear to be



Centaurs are small solar system bodies that cross the orbits of one or more of the giant planets, spending most of their time between Jupiter and Neptune. Because Centaurs are affected by the planets' gravity, their orbits are unstable — within a few million years, they are ejected or impact one of the planets. (Eris is currently located near the far end of its orbit, off the printed page.) *ASTRONOMY*: ROEN KELLY, AFTER DUNCAN STEEL

Chiron floats in the vastness of space in this illustration, surrounded by a wispy atmosphere that's fed by the jets of gas and dust emerging from the object's interior. DAN DURDA

RING SPOTTING



The rings of Chiron were discovered by taking advantage of stellar occultations. When a Centaur and its rings pass in front of a background star, the Centaur blocks the star's light. Astronomers can identify ring systems by the smaller dips in brightness that occur before and after the main dip, separated from it by the same interval in time. *ASTRONOMY*: ROEN KELLY, AFTER ESO/FELIPE BRAGA RIBAS/M. KORNMESSER

rings. This combination of exotica makes Chiron a scientific wonderland begging for study. And this trifecta of attractions is further enhanced by the discovery of carbon monoxide ice that is highly volatile (and therefore directly sublimating, or turning from a gas to a solid, into space), present either on Chiron's surface or emanating from its interior, or both.

But even that is not all. Chiron is also, by dint of its size, a critical missing link to understand how planetesimals, like the small KBO Arrokoth that the New Horizons spacecraft studied in the Kuiper Belt, aggregate into small planets like Pluto, Eris, Makemake, and Quaoar. Put more concretely, Chiron is about 10 times the size (and about 1,000 times the mass) of Arrokoth, but only one-tenth the size (and about one-thousandth the mass) of Pluto. From this perch between planetesimals and planets, Chiron and its kin offer us a glimpse of a critical, unexplored missing link in planet formation and evolution. No icy object formed in orbit around the Sun in this intermediate size range has ever been explored by any spacecraft.

The Centaurs are also ripe for spacecraft exploration for a more pragmatic reason: They represent a "shortcut" to the Kuiper Belt. What is meant by this? Simply put, as Kuiper Belt escapees now orbiting at much closer range, Centaurs can be explored much more easily than the Kuiper Belt itself.

Many Centaurs, including Chiron, are sometimes closer than even the orbit of Saturn. This means that the Sun's light is still strong enough for visiting spacecraft to rely purely on solar power to run their equipment. This is a major simplification over missions like New Horizons and Voyager, which required expensive nuclear power systems to supply electricity. And because they are three or more times closer to the Sun than KBOs, Centaurs are also more brightly lit, making it easier to image them and to measure their compositions and other properties. If that weren't enough, their closer positions also mean that spacecraft exploring them can communicate back to Earth at rates 10 to 100 times higher than what similar telecommunication systems could manage from the faraway Kuiper Belt. Together, these three important factors make it possible to explore Centaurs more easily, at lower cost, and with quicker flight times than missions to the Kuiper Belt itself.

Centaurus: A Centaur tour

Although no mission to Centaurs has yet been flown or even built, a variety of such missions have been studied and proposed in the past decade.

The easiest type of Centaur mission is a tour of several of them, making flybys of each to gain a broad understanding of these bodies as a group. As principal investigator, I led a team that studied such a mission, called Centaurus, from

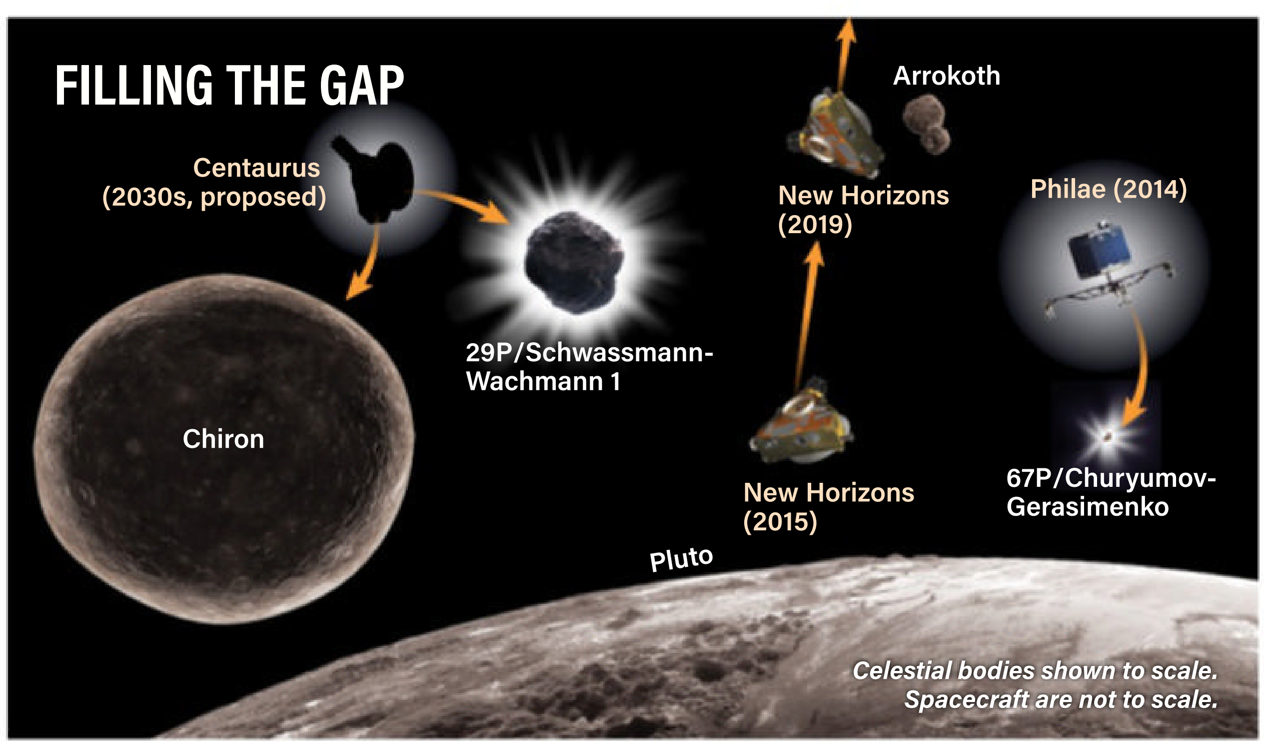
A Falcon 9 rocket sits on the launchpad at Vandenberg Air Force Base in California, in June 2019. SPACEX

CHIRON AND ITS KIN OFFER US A GLIMPSE OF A CRITICAL, UNEXPLORED MISSING LINK IN PLANET FORMATION AND EVOLUTION.

2017 to 2019, which we submitted to NASA's program of modestly budgeted Discovery-class missions. The two main team partners were my institution — the Southwest Research Institute — and the Caltech Jet Propulsion Laboratory. We found ways for Centaurus to fly by three or more Centaurs on the way to Chiron, sampling the diversity of the Centaur population in color, composition, size, activity, and ring systems.

The payload we selected for Centaurus included color and panchromatic visible imaging cameras that would carry out geological mapping and geophysics studies, as well as studies of Centaur satellites and rings. It also included an infrared composition mapping spectrometer to determine surface composition across each body, and an ultraviolet mapping spectrometer to measure the composition of their atmospheres and how quickly they are escaping their relatively gentle gravity. A radio science package rounded out the payload to study the density and thermal properties of each Centaur that it passed.

The solar-powered spacecraft we designed was based heavily on NASA's existing Discovery-class Lucy mission, built by Lockheed Martin. (Scheduled to launch in 2021, Lucy will crisscross the solar system on a tour of the distant Trojan asteroids, which share Jupiter's orbit.) Centaurus could be launched to the Centaurs using a SpaceX Falcon 9 or Falcon Heavy booster, as well as other similar heavyweight launchers including the United Launch Alliance Vulcan and Atlas V vehicles. Launch windows for Centaurus open in 2026 and persist for many years, without any need for third stages or electric propulsion. This low-cost, low-risk, science-rich mission would be able to carry out the first



Chiron and its fellow Centaur, 29P/Schwassmann-Wachmann 1 (SW1), fall in a size category of objects originating in the Kuiper Belt that have never been explored by spacecraft. Chiron is 137 miles (220 km) across and SW1 is 38 miles (60 km) in diameter — larger than Comet 67P/Churyumov-Gerasimenko and Arrokoth, but smaller than planets like Pluto. Studying the geology and structure of Centaurs could help scientists better understand what happens when planetesimals like Arrokoth glom together to form planets. *ASTRONOMY*: ROEN KELLY, AFTER DAN DURDA. PLUTO: NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/SOUTHWEST RESEARCH INSTITUTE

RINGED WORLDS OF THE SOLAR SYSTEM

When I was a kid with an interest in space and astronomy, I was often irked by cartoons and movies set in space because they usually depicted the skies on alien planets as full of rings — yet only one ringed planet was then known, Saturn.

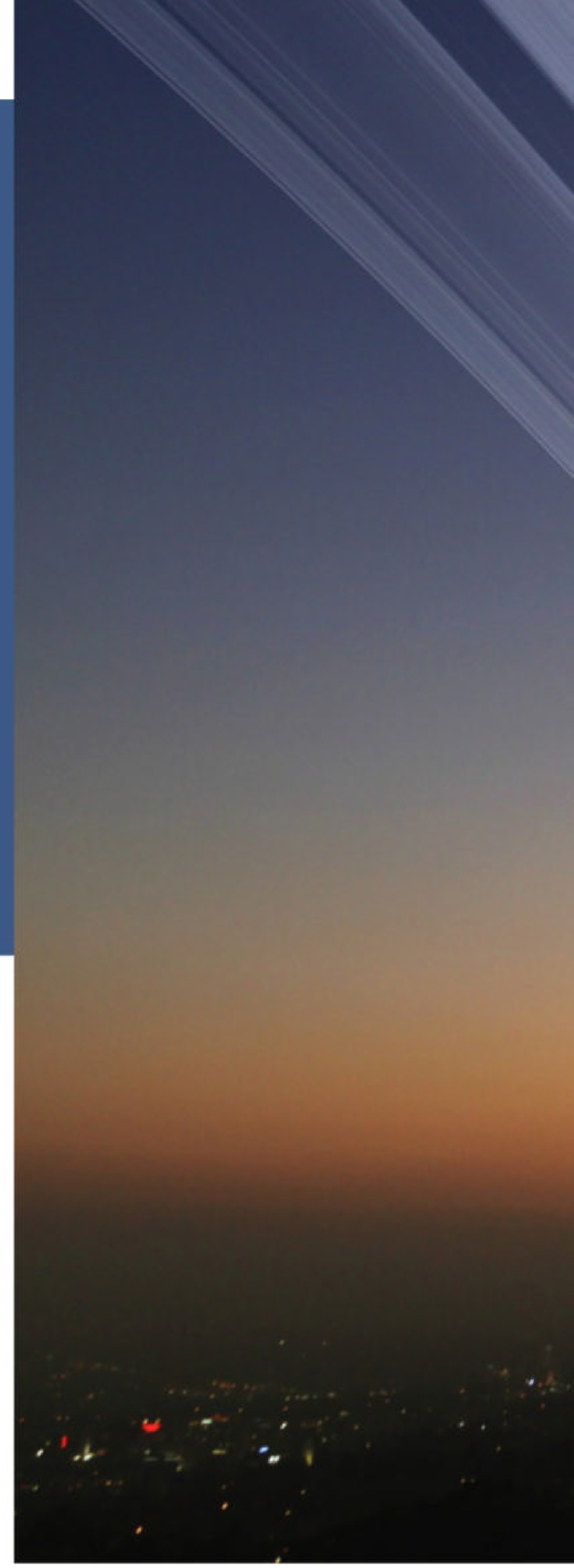
But in 1977, the same year that Chiron was discovered, an MIT planetary astronomy group led by the late Jim Elliot discovered that Uranus also has rings.

That discovery was made using the technique of stellar occultation — watching Uranus cross in front of a background star. The rings blotted out some of the star's light, causing drops in brightness on both sides of the planet.

By the late 1980s, researchers also had found ring systems around Jupiter and Neptune, discovered by a combination of passing spacecraft and stellar occultations. Rings, it seems, are common among giant planets — an irony that occurred to me many times in the 1990s and 2000s when my kids watched cartoons with ringed planets everywhere.

Over the past three and a half decades, planetary astronomers searched for rings around asteroids, Mars, Pluto, and other bodies, but found nothing. But in 2013, Felipe Braga-Ribas, then at the Observatório Nacional in Rio de Janeiro, led a team observing a stellar occultation of a large Centaur, Chariklo, and found two rings orbiting it. Soon, rings or dusty ringlike structures were also discovered around the Kuiper Belt planet Haumea and around another large Centaur, Chiron.

As a result, we now know that solid bodies, even those only hundreds of miles in diameter, can sport rings just as well as gas giant planets can. But unlike the giant planets' rings, none of these seemingly more exotic ring systems has been visited by a spacecraft for close-up examination. The hoped-for exploration of Chiron by Centaurus would change that. *—S.A.S.*



exploration of Centaurs by the early 2030s, reaching Chiron itself by the late 2030s. And beyond the known Centaurs we can explore on the way to Chiron, the National Science Foundation's upcoming Vera C. Rubin Observatory — which should begin operations in 2023 — could discover new Centaurs that we could add to further enrich Centaurus' itinerary.

Another Centaur mission option that has been studied in the past would place a spacecraft in orbit around a Centaur for an extended investigation lasting a year or more. However, this is hard to do in conjunction with a tour of multiple Centaurs, so it doesn't allow for exploring the diversity of this rich population like the multiple-flyby Centaurus mission does. It would also be more expensive — it would require substantially more onboard propulsion in order to slow down enough to get into orbit and would likely also require nuclear power to run its instruments. Therefore, even though such a mission can study a single target in depth in ways a flyby mission like Centaurus can't, an orbiter doesn't really make as much sense for a first reconnaissance of the Centaurs as does a tour of multiple Centaurs.

An international opportunity

Unfortunately, NASA didn't select Centaurus for development, though the agency did give it high scores and low risk ratings. NASA also didn't select another Centaur mission, Chimera, which competed in the most recent Discovery round of consideration and would have targeted the Centaur 29P/Schwassmann-Wachmann 1. As a result, the selection of a NASA mission to make the inaugural exploration of Centaurs is now at least years away at best. It would be unlikely to even launch before this decade is out and wouldn't reach Chiron until the 2040s.

But there is another possibility, a way to circumvent that long delay. Perhaps a group of scientific organizations and space and science agencies could band together to mount Centaurus. Such a collaboration, if formed in the next couple of years, could result in a mission launched by the late 2020s to yield results in the 2030s. And because such a mission can be accomplished on commercial launch vehicles without the costly and complicated need for nuclear power supplies, there is no impediment — other than desire and funding commitment — to getting it underway.

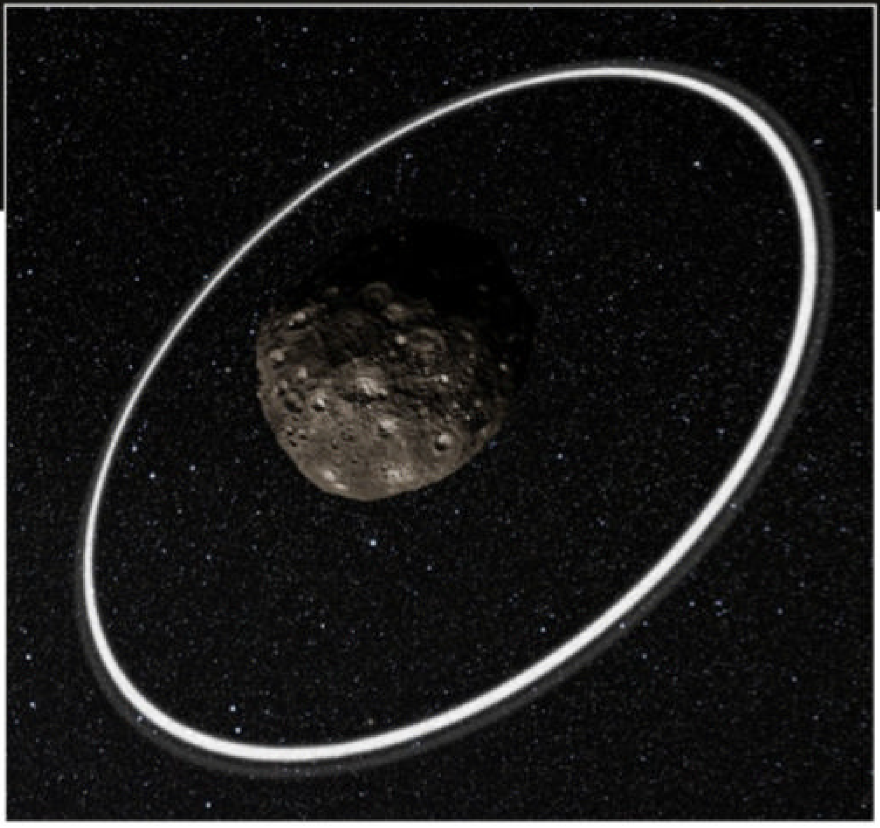
Never before has any nation except the U.S. launched missions to explore outer solar system bodies. Imagine the pride, the prestige, the scientific return, and the inspiration that such a multinational collaboration could generate.

As a scientist who spent 17 years working from idea to liftoff to see the first mission to Pluto launched against much tougher odds and obstacles, I'll just close here by simply saying this: Centaurus could soon be underway as an international enterprise, and beyond its

incredible scientific potential, Centaurus offers the chance to excite a new generation of children all around the world to the faraway exploration of ancient and exotic worlds.

Ad Astra! Ad Centaurs! Go Centaurus!

S. Alan Stern *is a planetary scientist and a member of the U.S. National Science board. He has led 14 NASA flight missions and scientific instruments, including New Horizons to Pluto and the Kuiper Belt.*



ABOVE: Rings can make even familiar landscapes appear alien, as in this illustration that depicts the landscape of Los Angeles from Griffith Observatory, if Earth had a ring system. KEVIN GILL/CC BY 2.0

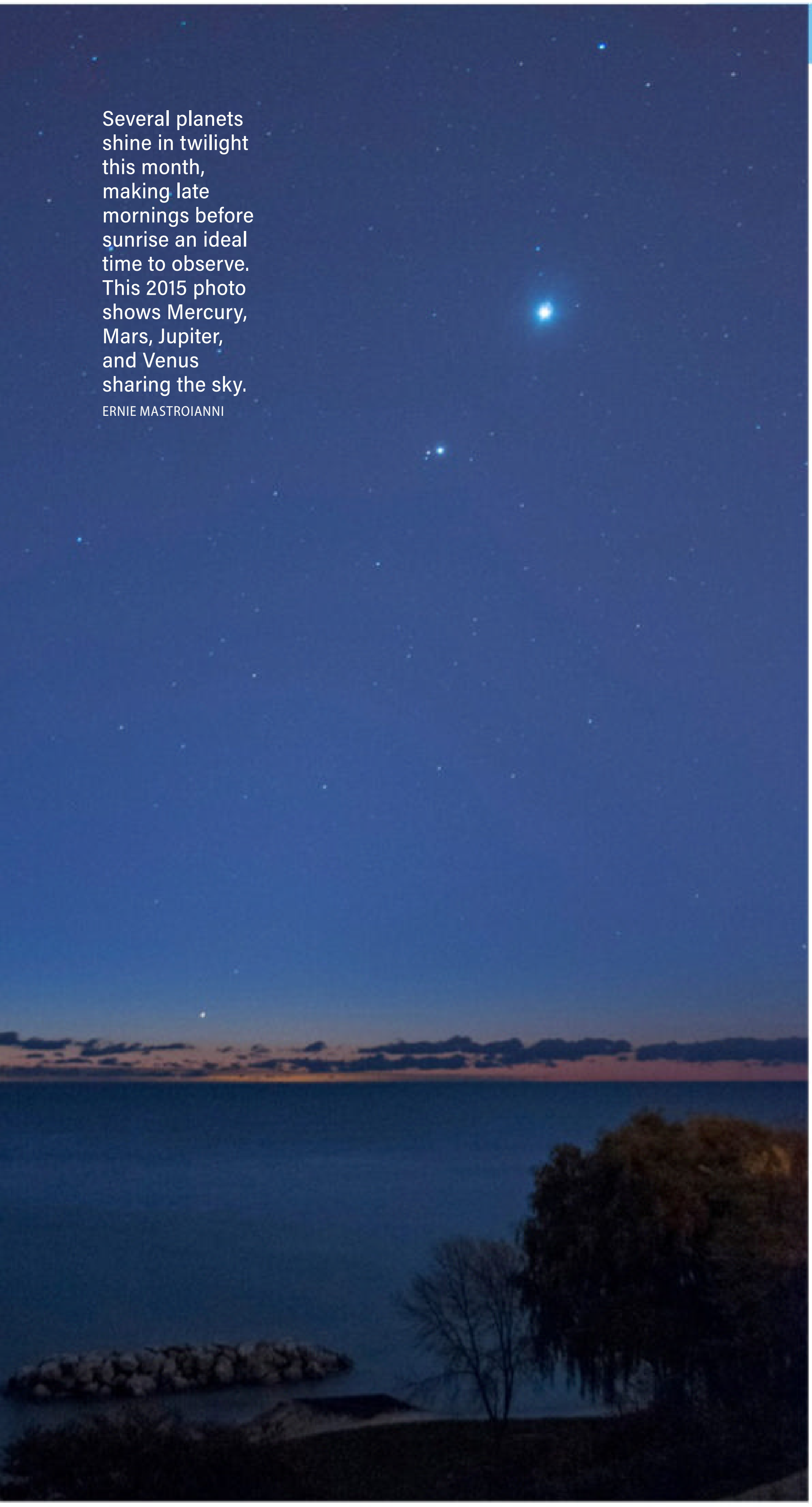
LEFT: Chariklo's ring system, seen here in an artist's concept, was the first in the solar system to be found around a body that is not a giant planet. ESO/L. CALÇADA/M. KORNMESSER/NICK RISINGER (SKYSURVEY.ORG)

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

MARCH 2021
Late mornings, early evenings



Several planets shine in twilight this month, making late mornings before sunrise an ideal time to observe. This 2015 photo shows Mercury, Mars, Jupiter, and Venus sharing the sky. ERNIE MASTROIANNI

During March, Mars lingers in the evening sky as a wonderful bright object as it crosses Taurus. Most of the planetary action is now in the predawn sky, with three planets congregating there: Jupiter, Saturn, and Mercury. Watch their relative dance as they jostle positions each morning.

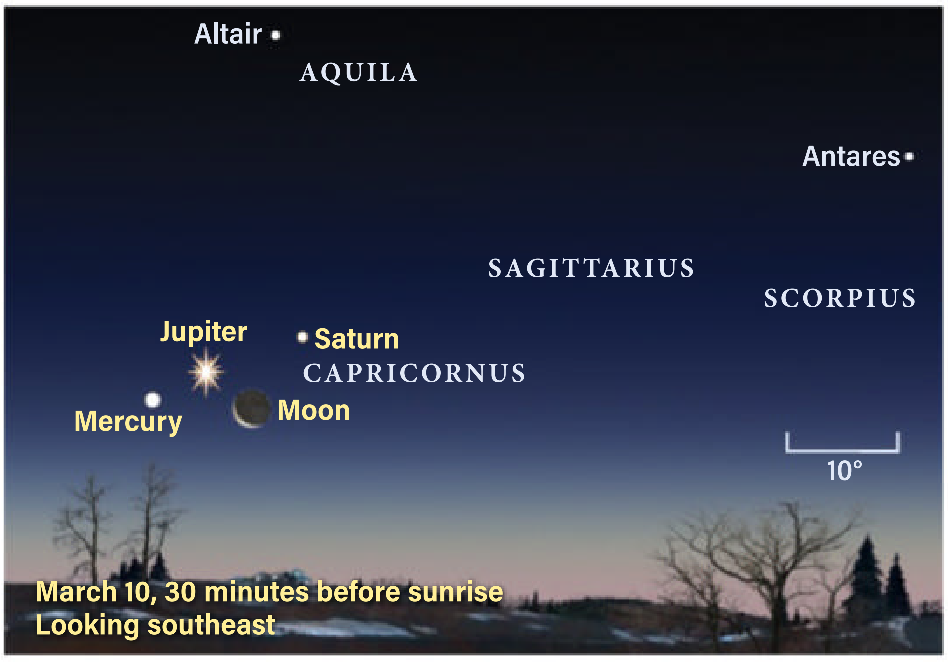
Mars is a dramatic and bright addition to Taurus; it is the first planet to come into view after sunset. The Bull now hosts two objects of first magnitude: the fine red giant star Aldebaran (magnitude 0.8) and Mars, which fades from magnitude 0.9 to 1.3 during March. As March opens, the Red Planet is beautifully situated near the Pleiades (M45).

Mars stands about 3° due south of M45 on March 1, and remains in the vicinity for a few days as it drifts slowly eastward. The planet cruises north of the Hyades star cluster during the third week of the month. A lovely crescent Moon joins in on March 18 and 19. On the 18th, the Moon is 5° from M45 and Mars stands 8° northeast of our satellite. The following evening, Mars stands less than 4° west of the Moon, forming a nice triangle with Aldebaran to the south.

The Red Planet continues eastward, passing 7° due north of Aldebaran on March 22. By the 31st, it stands near the sparse star cluster NGC 1746 — a nice object when viewed in binoculars, made all the more striking with Mars glowing nearby at magnitude 1.3.

Mars is a tiny object in telescopes, spanning 6" as March opens and shrinking by 1" by the end of the month. At this apparent size, Mars is heavily affected

The morning lineup



Mercury, Jupiter, and Saturn jockey for position all month. On March 10, they share the morning sky with a delicate crescent Moon. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

MARS is in Taurus this month. The Red Planet passes 7° due north of bright, ruddy Aldebaran the evening of March 22.

by turbulence in our atmosphere. Even at an elevation above 50° soon after dusk, its features are challenging without a large telescope. Observers who have developed their skills with video imaging may give it a try, but it truly is the luck of the draw when it comes to the seeing conditions that will govern the results you might achieve.

Uranus is lower in the sky than Mars and you'll have to wait for full darkness to find it. Even then, only binoculars or a small telescope will reveal the ice giant. Uranus shines at magnitude 5.9, which is near the naked-eye limit for perfect skies (a rarity). An hour after sunset on March 1, Uranus stands nearly 40° high in the western sky. It's 10° south and slightly east of Hamal, the brightest star in Aries the Ram.

Since Uranus lies in a sparse region of the sky, another useful visual guide is to drop directly below the Pleiades until you're level with Hamal and begin your binocular search there, scanning just below the line connecting Hamal with the 3rd-magnitude star Menkar (Alpha [α] Ceti) in Cetus the Whale. In 7x50 binoculars, you'll find a line of three stars close to 6th magnitude and spanning 5° — these are 27, 29 and 31 Arietis. Uranus is the brightest object below the middle star (29 Arietis).

— Continued on page 38

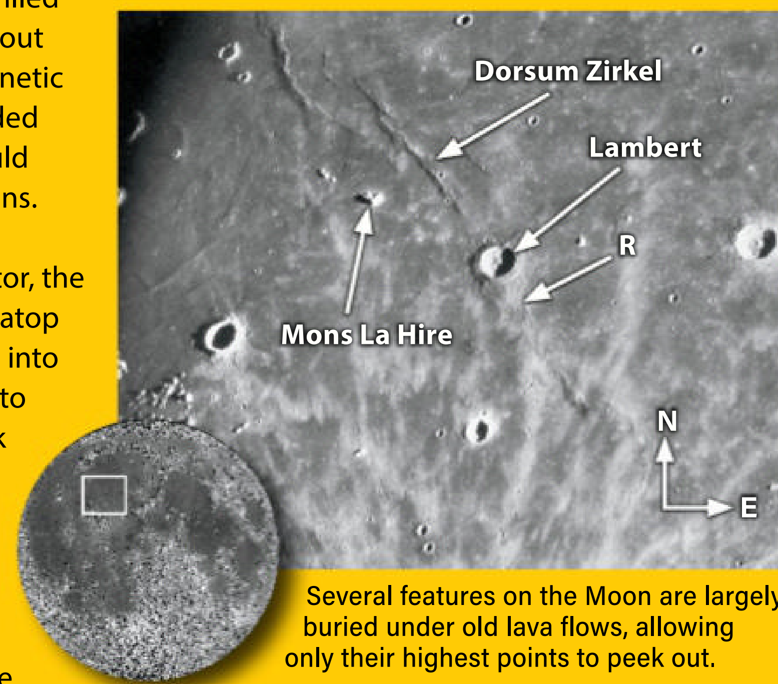
RISING MOON | The three towers

EVEN YOUTHFUL FEATURES on the Moon are still old. The great molten floods that filled the giant Imbrium impact basin ended about 1.1 billion years ago. We know that the frenetic inner solar system bombardment had ended before that, otherwise the lava plains would contain as many craters as the other regions.

West of the spectacular flooded crater Archimedes, itself north of the lunar equator, the small impact crater Timocharis stands out atop the flat plain on March 20. Lambert comes into view on the 21st, casting a long shadow into the still-darkened half of our satellite. Look carefully just to its south and you should see the ghostly ring of Lambert R. This circular feature is most likely an old crater buried in lava, whose peaked rim just manages to deform the surface. Its gentle slopes are visible only with a low Sun angle — in a couple of nights, the thin shadows will have disappeared completely.

Standing out in the darkness northwest of Lambert is Mons La Hire, whose isolated peak catches the Sun's rays a lunar day before its base experiences sunrise. Lunar scientists William Hartmann and Charles Wood proposed in 1971 that La Hire is related to other peaks on the north side of Mare Imbrium, including Piton and Pico. Giant impacts often form multi-ring structures, and the tallest ring is marked by this trio of towers. The rest of the quasicircular chain is buried under the lava, but, like Lambert R, it deforms the surface into ridges. One such ridge segment is Dorsum Zirkel, heading off to the northwest of Lambert. This, too, will disappear from sight under a higher Sun, so don't wait to find it.

Lambert, Mons La Hire, and Dorsum Zirkel



Several features on the Moon are largely buried under old lava flows, allowing only their highest points to peek out. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Solar system dust

FOR A SECOND MONTH in a row no major meteor showers occur, although the background sporadic rate provides an average of seven meteors per hour. The main feature this month is the zodiacal light, which enjoys prime viewing time in March because the ecliptic is inclined steeply to the western horizon.

Once the long, low arc of twilight has almost gone from the west, notice the additional glow stretching up through Aries and Taurus. Observers in dark locations — and preferably at higher elevations — are favored with a view of this elusive glow.

The zodiacal light comes from sunlight reflecting off billions of dust particles that pervade the solar system — the remnants of eons of dusty comets ejecting their mass. Whenever Earth encounters these trails, we see a meteor shower. But in March, we instead see the vast expanse of this dust stretched out across space. Aim for the moonless period of the first two weeks of the month to search out this phenomenon; the last two days of March are also favorable.

Cometary debris

Best seen in the evening after sunset, the zodiacal light is a cone-shaped glow somewhat fainter than the Milky Way and aligned with the ecliptic. STEVE CULLEN

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. March 1
10 P.M. March 15
9 P.M. March 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

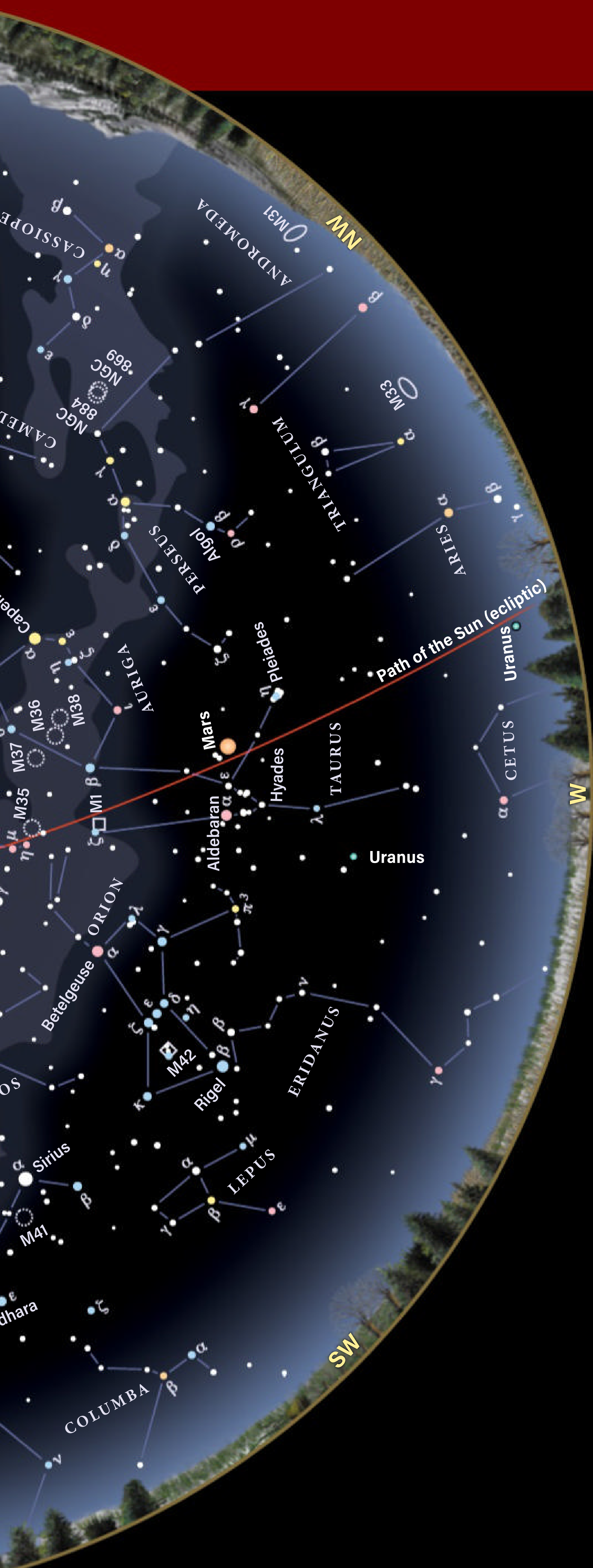
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



MARCH 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

2 The Moon is at perigee (227,063 miles from Earth), 12:18 A.M. EST

4 Asteroid Vesta is at opposition, 1 P.M. EST

5 Mercury passes 0.3° north of Jupiter, 2 A.M. EST

Last Quarter Moon occurs at 8:30 P.M. EST

6 Mercury is at greatest western elongation (27°), 6 A.M. EST

9 The Moon passes 4° south of Saturn, 6 P.M. EST

10 The Moon passes 4° south of Jupiter, 11 A.M. EST

Neptune is in conjunction with the Sun, 7 P.M. EST

The Moon passes 4° south of Mercury, 8 P.M. EST

13 New Moon occurs at 5:21 A.M. EST

16 The Moon passes 3° south of Uranus, 10 P.M. EDT

18 The Moon is at apogee (251,812 miles from Earth), 1:03 A.M. EDT

19 The Moon passes 1.9° south of Mars, 2 P.M. EDT

20 Vernal equinox occurs at 5:37 A.M. EDT

21 First Quarter Moon occurs at 10:40 A.M. EDT

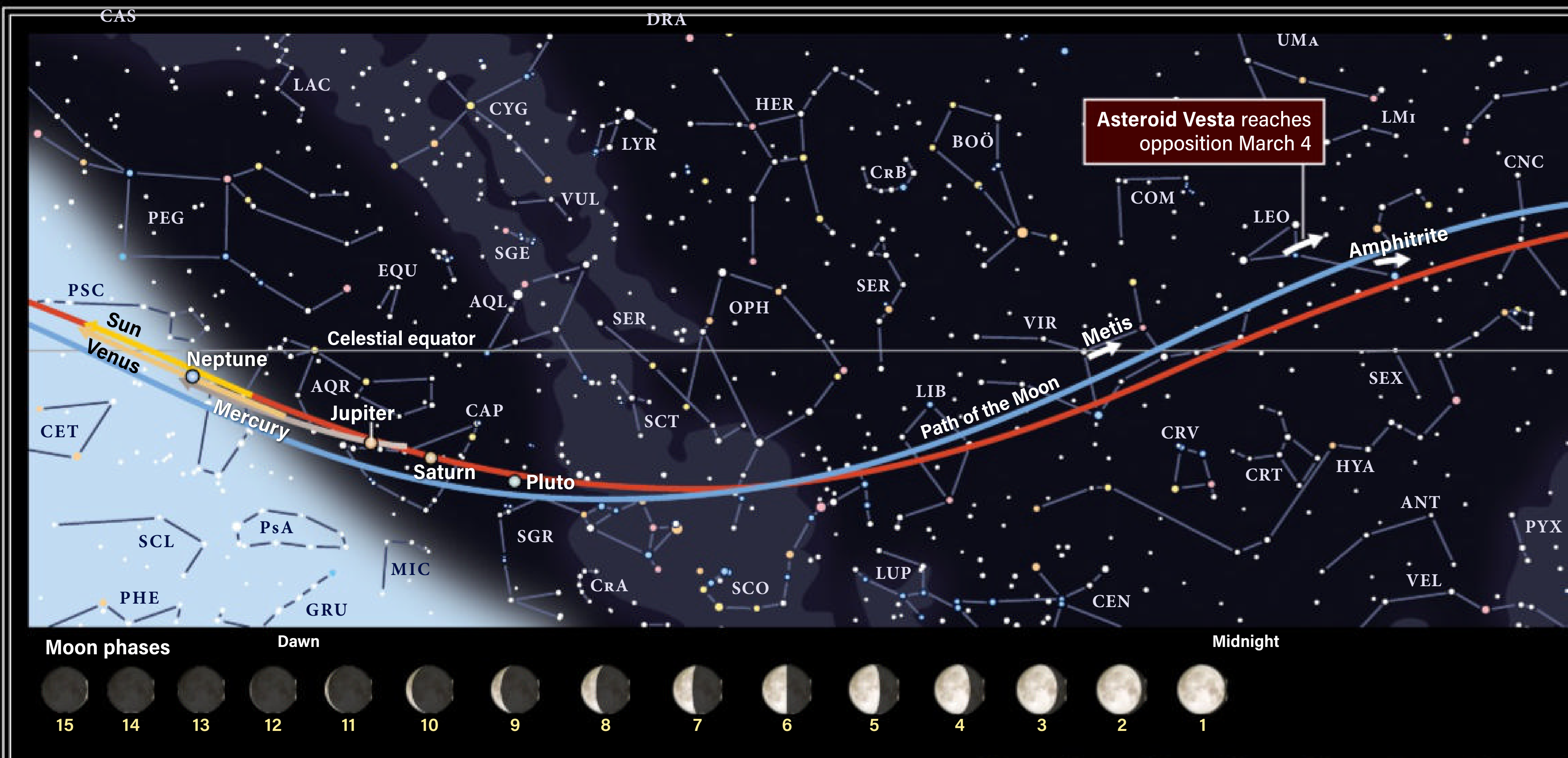
22 Mars passes 7° north of Aldebaran, 8 P.M. EDT

26 Venus is in superior conjunction, 3 A.M. EDT

28 Full Moon occurs at 2:48 P.M. EDT

30 The Moon is at perigee (223,886 miles from Earth), 2:16 A.M. EDT

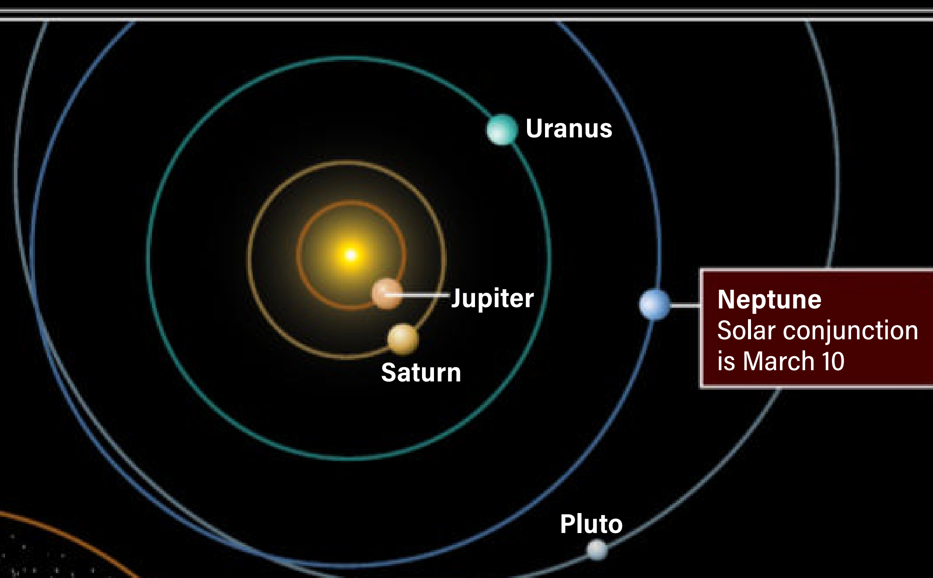
PATHS OF THE PLANETS

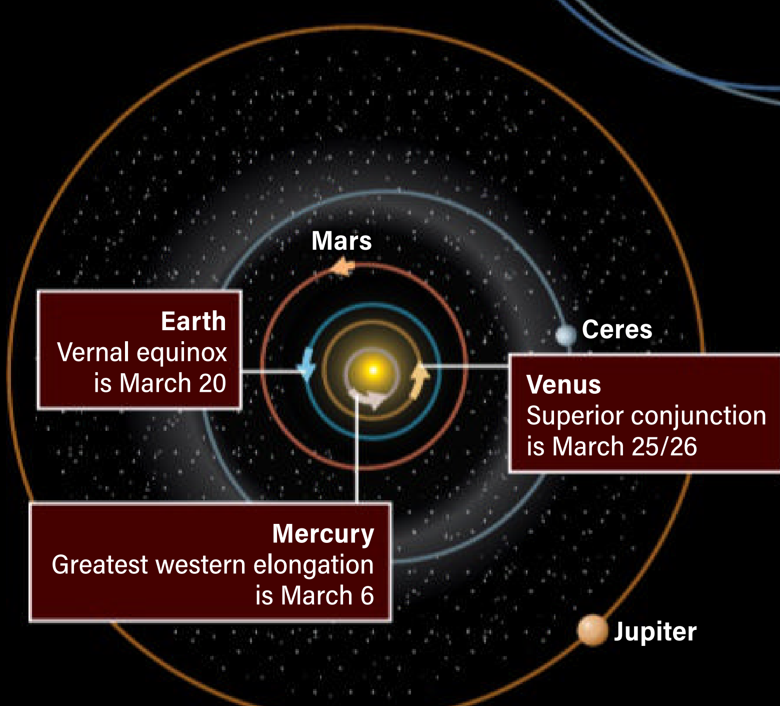


To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

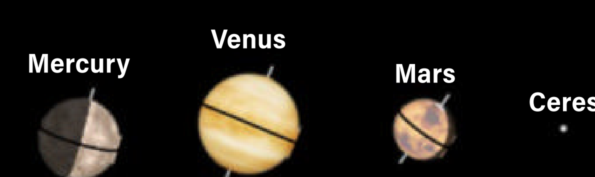
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

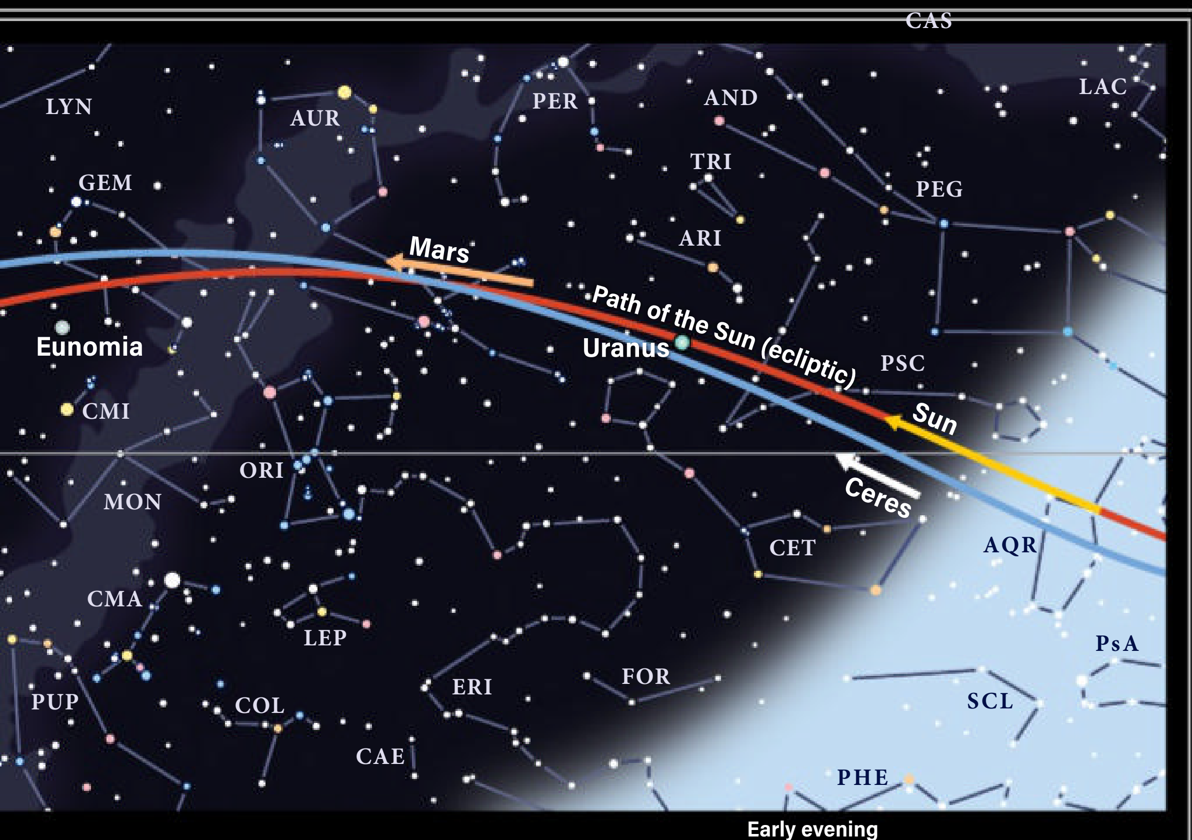
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.

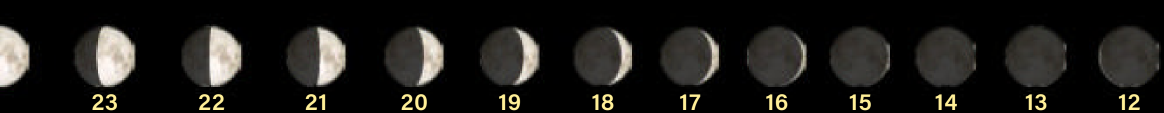


PLANETS	MERCURY	VENUS
Date	March 1	March 15
Magnitude	0.3	–3.9
Angular size	7.8"	9.7"
Illumination	47%	100%
Distance (AU) from Earth	0.859	1.718
Distance (AU) from Sun	0.443	0.727
Right ascension (2000.0)	21h04.5m	23h31.0m
Declination (2000.0)	–16°11'	–4°41'

MARCH 2021

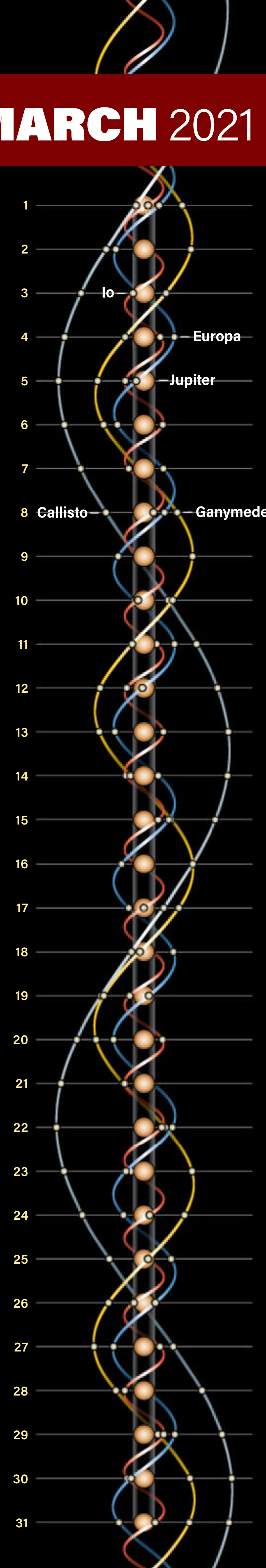
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

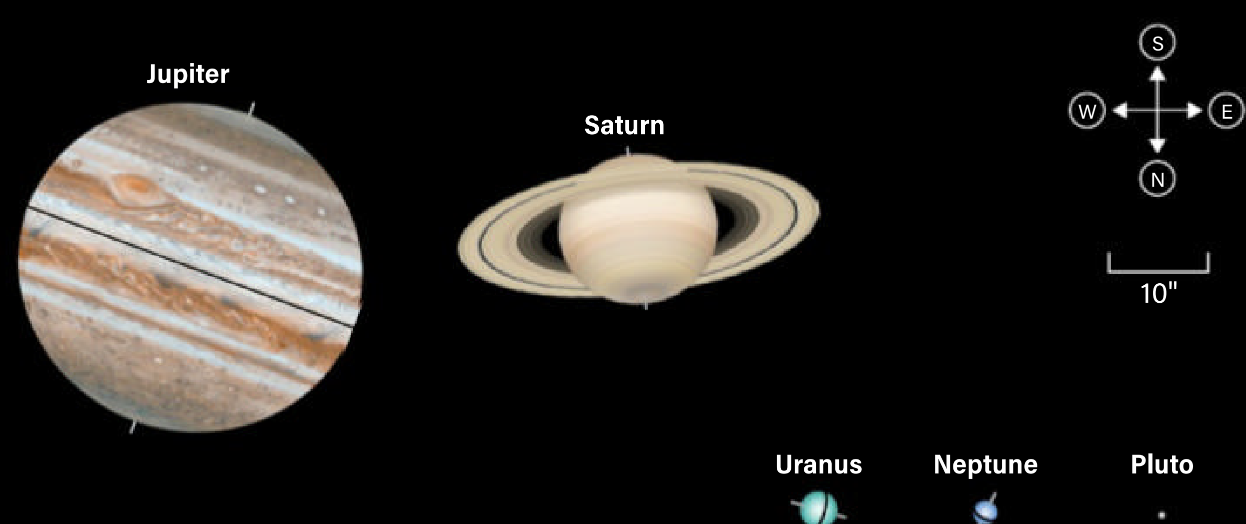




JUPITER'S MOONS

Dots display positions of Galilean satellites at 6 A.M. EDT on the date shown. South is at the top to match the view through a telescope.





MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
March 15	March 15	March 15	March 15	March 15	March 15	March 15
1.1	9.1	–2.0	0.6	5.9	7.8	15.2
5.8"	0.3"	33.7"	15.6"	3.4"	2.2"	0.1"
90%	100%	100%	100%	100%	100%	100%
1.601	3.873	5.855	10.657	20.471	30.918	34.752
1.598	2.928	5.072	9.975	19.763	29.926	34.240
4h15.6m	0h41.6m	21h28.2m	20h48.7m	2h22.7m	23h26.8m	19h53.3m
22°46'	–3°33'	–15°34'	–18°19'	13°45'	–4°45'	–22°14'

 — Continued from page 33

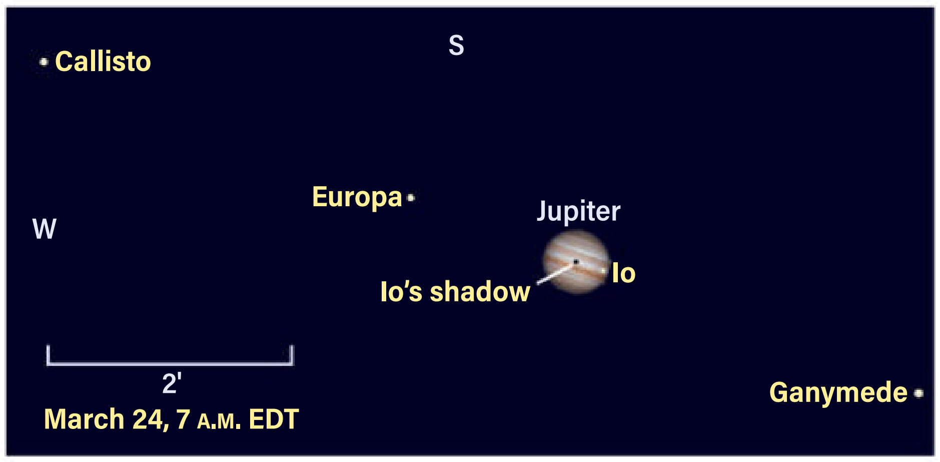
WHEN TO VIEW THE PLANETS

EVENING SKY
Mars (west)
Uranus (west)

MIDNIGHT
Mars (west)

MORNING SKY
Mercury (east)
Jupiter (east)
Saturn (southeast)

A twilit transit



Before the Sun rises on March 24, you can catch Jupiter's moon Io transiting the planet's face, preceded by its shadow. See how long you can follow the show in the brightening twilight, but take care as sunrise approaches.

That star makes the path of Uranus easy to spot during the month. As March opens, Uranus lies 3.3° below 29 Arietis. By mid-March, the distance shrinks to 2.7°. On March 31, the planet and star are separated by only 2°. On March 16, a thin crescent Moon lies on the border of Aries and Cetus, while Uranus lies 3.3° north of our satellite. With a telescope, Uranus is challenging, spanning a tiny 3".

Late evenings in March are devoid of bright planets. However, the middle of the night is a great time to search for minor planets. In particular, 4 Vesta, the brightest asteroid, reaches opposition March 4. Vesta was discovered in neighboring Virgo March 29, 1807, by German astronomer Heinrich Olbers. It was his second discovery, after finding 2 Pallas five years earlier.

Vesta currently lies in the tail section of Leo the Lion. At magnitude 5.8, it's an easy binocular object, and this spring is your best opportunity to spot this fascinating asteroid. On the 4th, you'll find Vesta in the same binocular field of view as 3rd-magnitude Chertan (Theta [θ] Leonis). Center the star in binoculars and you'll easily spot Vesta 1.3° to the northeast. There are no other stars rivaling Vesta in brightness in the area, making it easy to identify.

Vesta's orbital path carries it northwestward at about 0.25° per day; it stands 1.3° due north of Chertan on March 8. It passes 8' due south of a 6th-magnitude field star on March 16, then lands 2.1° due east of 51 Leonis on March 31, in the sparsely populated central region of the constellation. Look for the shallow triangle the pair makes with 60 Leonis to the east — both stars and Vesta fit inside the field of view of 7x50 binoculars.

Vesta remains visible all night. Follow it until summer, when the minor planet spends a week in June within 1° of M65 and M66 after reaching its stationary point in April and making an about-face through the constellation.

Saturn is the first planet to peek over the southeastern horizon in the predawn hour. It rises about 5:10 A.M. local time on March 1, just as the sky begins to show the first signs of twilight. Mercury, a bit farther east, joins 15 minutes later, followed by Jupiter just after 5:30 A.M. local time. **Jupiter** easily outshines its fellow planets at magnitude –2.0. Saturn and Mercury are

4 Vesta was the fourth asteroid discovered, and the second spotted by Heinrich Olbers.

COMET SEARCH | A newcomer rises with the dawn

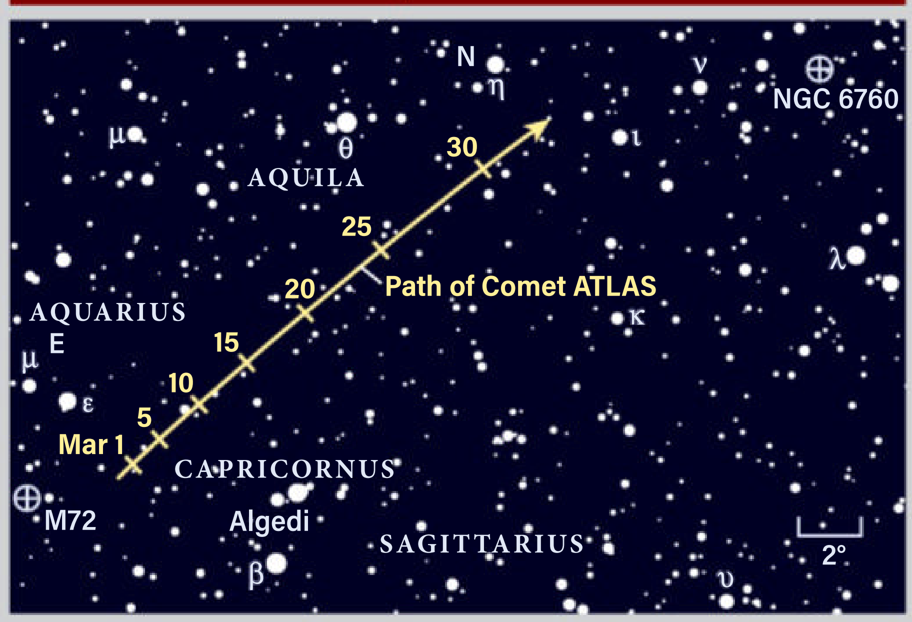
WAKING UP from its thousand-year sleep, Comet C/2020 R4 (ATLAS) is competing for the top of the telescopic comet list this spring. It's visiting from the Kuiper Belt, having traveled some four times Pluto's distance to reach us. The comet was discovered September 12 by the Asteroid Terrestrial-impact Last Alert System search program (also known as ATLAS).

Nicely timed to cap off a long night of deep-sky Messier marathoning midmonth, ATLAS floats in near M72. Your jumping-off point to reach the 9th-magnitude globular cluster is the naked-eye double star Algedi (Alpha[1] [α^1] and Alpha[2] [α^2] Capricorni); you may as well first jog northwestward to pick up the slightly fainter comet.

The two objects share a few other characteristics that are best seen at magnifications above 100x. Both should be mostly round, brighter in the middle, and fading quickly to a soft edge. Perhaps in a big scope there will be a hint of green from the ionized gas in the comet's coma. Boost the power some more to see if you can detect that the southeast flank of the comet is more sharply defined. This is where the solar wind pushes back the dust in a bow wave.

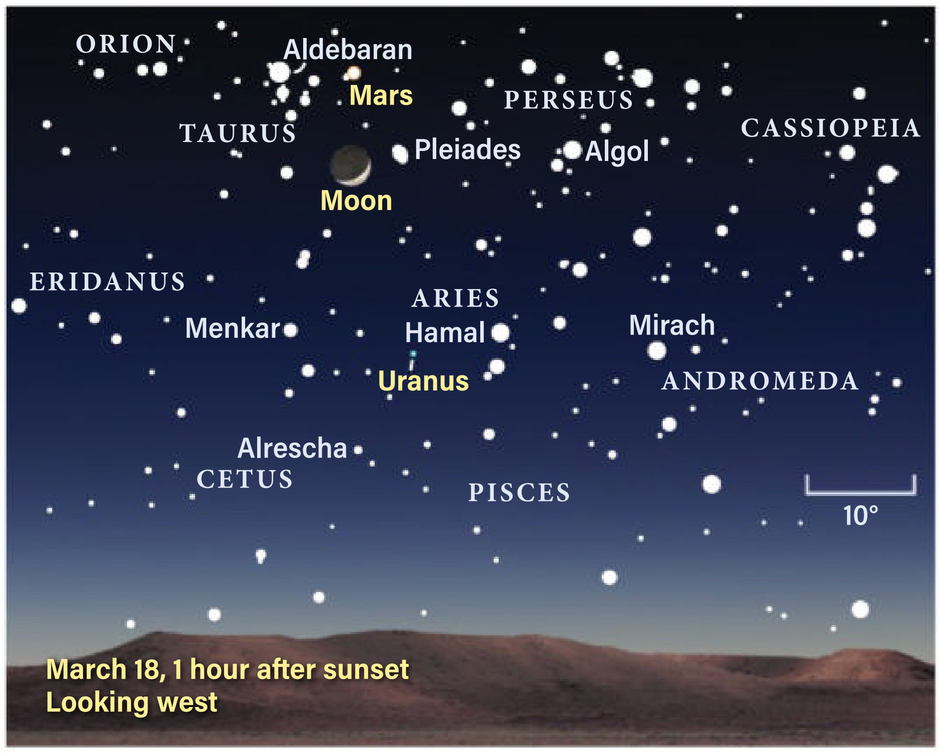
In contrast to ATLAS' brief passage, amateur astronomers will soon be treated to C/2017 K2 (PanSTARRS)'s two-*year*-long appearance!

Comet C/2020 R4 (ATLAS)



Comet C/2020 R4 (ATLAS) is visiting from the Kuiper Belt. Find it near M72 early in March and drawing closer to NGC 6760 later in the month.

A rich evening spread



Mars spends its time in the rich region of Taurus during March. Lower in the sky, Uranus can still be found using the stars Menkar and Hamal as guides.

dimmer, shining at magnitude 0.6 and 0.3, respectively.

With each subsequent morning, the three planets briskly change relative positions. Mercury is following the Sun along the ecliptic and lies on the far side of the solar system, moving toward a springtime superior conjunction. Its visibility declines after the middle of March. Jupiter and Saturn are climbing away from their respective conjunctions with the Sun, improving their visibility each day.

Mercury starts the month standing 2.5° west of Jupiter. Its March 11 conjunction with Jupiter takes place in daylight, but the mornings before and after are prime times to view the pair. By March 4, the pair stands 0.6° apart, and the following morning, only 0.4° separates the planets and Mercury has brightened to 0.2. Mercury, the closer of the two at 0.93 astronomical units from Earth, spans 7" and is 55 percent lit. (One astronomical unit, or AU, is the average Earth-Sun distance.) Jupiter lies more than six times the distance of Mercury from Earth — 5.9 AU — yet spans a much larger 33".

A slim crescent Moon joins the scene from March 9 to 11. Saturn stands 7.5° northeast of the 26-day-old Moon on the 9th. The following morning, the Moon has glided along the ecliptic and you'll find Jupiter standing 5° north-northeast of our natural satellite, while Mercury shines 4.5° due east of Jupiter.

By March 14, when daylight saving time takes effect, Saturn is up by 5:20 A.M. local time, followed by Jupiter half an hour later. Mercury lies in much brighter twilight, rising around 6:20 A.M. local time. You have a narrow window to view the innermost planet, now at magnitude 0, before twilight drowns it out. Look for it about 3° high around 6:40 A.M. local time on March 14. You can follow Mercury's descent into brighter twilight each consecutive morning, although you'll need a clear eastern horizon to do so.

Saturn and Jupiter become easy objects low in the southeast by the end of March. Both lie in Capricornus the Sea Goat. Saturn rises around 4:20 A.M. local time on March 31, with Jupiter still trailing by about 30 minutes. As twilight begins, both planets lie below 15° altitude, a difficult location for telescopic observations due to poor seeing conditions. They're now almost 12° apart. Both planets become easier telescopic targets next month.

Neptune reaches superior conjunction with the Sun March 10, and **Venus** reaches superior conjunction March 26. Neither planet is visible this month.

Martin Ratcliffe *is a planetarium professional and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS

The best rock is back

SUBURBAN BINOCULAR TRACKING has returned! This month, Asteroid 4 Vesta cracks the top 10 brightest lights in all of Leo's hindquarters. That means experienced observers can step outside without dark adapting, look to the east with binoculars, and identify a space rock in five minutes.

If you're relatively new to matching charts to the sky and handling binos or a small scope, then slow down and enjoy this easy treasure hunt. The blue-white luminary in this region is Regulus, whose poetic Latin name is *Cor Leonis*, the heart of the lion. Look to its lower left (northeast) for a triangle of bright stars: Chertan, Zosma, and Denebola. These anchor a sketch — use them as a frame in which to place the other starlike object, Vesta, every other night.

Noticing the 6th-magnitude main-belt asteroid move in one three-hour session is tough, requiring a scope at 150x or so. The best window is from the 13th to the 17th, when Vesta oh-so-slowly oozes between a widely set duo of field stars with magnitudes 6.3 and 6.8.

The fourth body discovered in the main belt, Vesta is roughly 300 miles across, half the size of dwarf planet 1 Ceres. NASA's Dawn mission orbited Vesta for almost a year from 2011 to 2012, finding evidence supporting the proposal that some meteorites recovered on Earth were long ago blasted off its surface.

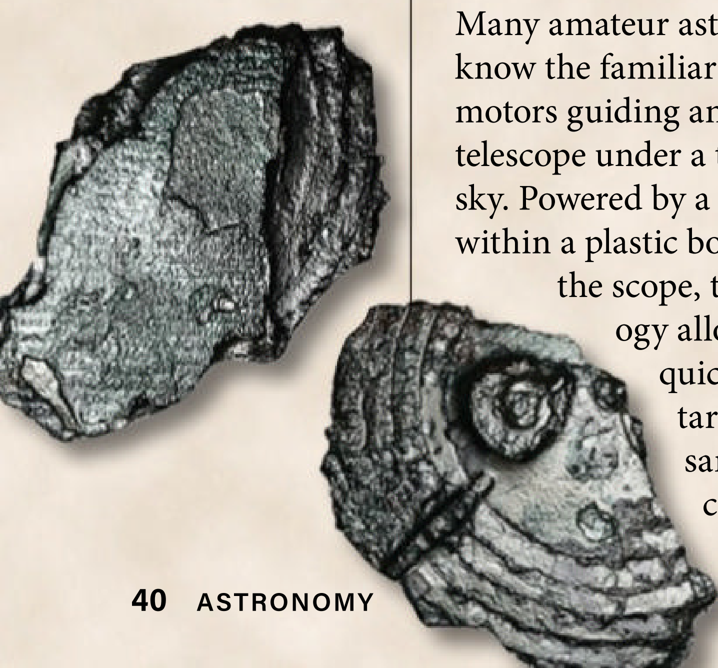
Easy viewing

Vesta sails through the hindquarters of Leo the Lion this month, passing near several bright stars and galaxies.

Dissecting an ANCIENT COMPUTER

The Antikythera mechanism was constructed some 2,000 years ago. But its complex and intricate design still baffles researchers. BY RAYMOND SHUBINSKI

RIGHT: The Antikythera mechanism was an ancient Greek analog computer used to track and predict celestial motion. Pieces of the device at the National Archaeological Museum in Athens, Greece, are seen here. JOY OF MUSEUMS/ WIKIMEDIA COMMONS



BELOW: The primary fragments of the Antikythera mechanism (seen throughout this article) are lettered A through G. Researchers have also identified and numbered 75 additional small pieces. ANTIKYTHERA MECHANISM RESEARCH PROJECT

Many amateur astronomers know the familiar thrum of small motors guiding an automated telescope under a tranquil night sky. Powered by a computer within a plastic box attached to the scope, this technology allows for the quick and accurate targeting of thousands of popular celestial objects. It's almost like having the cosmos in a box.

Although it may seem that the ability to use a computer to track the Moon, planets, and stars is a modern development, in reality, it dates back at least two millennia. In what must have been a collaboration between an astronomer-mathematician and a master craftsman, an ancient analog device was built that could track the heavens. Now known as the Antikythera mechanism, its creators designed it to capture the known cosmos in a wood and bronze container about the size of a shoebox.

In the first century B.C., a massive Roman cargo ship was caught in a storm near an island now called Antikythera. Located at the edge of the Aegean Sea, about halfway between southern

Greece's Peloponnese peninsula to the north and Crete to the south, this island was the only place to seek safety. The ship, bound for Rome, was more than 150 feet (46 meters) long and built to carry grain. But on that day, it was stocked with treasure and plunder from across the Greek world. As the storm pummeled the vessel, it began to sink. The crew abandoned ship; not everyone survived. By the time the weather finally eased, the ship, along with its precious cargo, was lost.

At least, it was lost until the spring of 1900, when a similar storm likewise forced a small Greek boat to seek shelter near Antikythera's shores. But this vessel and its crew of sponge divers survived. Once the seas were calm, one of the divers, wearing a bulky dive suit and copper helmet, slipped over the edge of his ship. He quickly returned with an amazing discovery. The seafloor was littered with pieces of bronze and marble statues. Soon after, a nine-month salvage operation kicked off. Salvagers eventually recovered thousands of broken and fragmented objects. Among these treasures was an unappealing lump of corroded bronze presumed to be part of a statue. It was so mundane, in fact, it was almost tossed back into the water.

The recovered items were sent to the National Archaeological Museum in Athens. In 1902, investigators examined pieces of the corroded bronze artifact. They noticed Greek writing and intermeshed gears. The "discovery" was soon reported to the local newspaper, putting a century-long investigation into motion.

Early investigators assumed the Antikythera mechanism was some sort of clock, calculating device, or navigational instrument of Greek origin. Along with clearly corroded gears, they noted several Greek inscriptions. One bit of text reading "Rays of the Sun" clearly hinted at a celestial connection, but many questions remained. What was such a device doing on a 2,000-year-old ship? What was its purpose? And who could have constructed such a seemingly complex object a millennium before such geared devices were commonplace? Academics struggled in vain to answer these queries for years — until 21st-century technology revealed the marvels of this astronomical artifact.

TOP LEFT: The island of Antikythera is nestled about halfway between Greece's Peloponnese peninsula and Crete. *ASTRONOMY*: ALISON MACKEY, AFTER NASA

BELOW LEFT: Discovered in 1900, the Antikythera mechanism is still an object of intense and ongoing study. Here, a researcher investigates an artifact at the site of the wreck. BRETT SEYMOUR/EUA/WHOI/ARGO

Solving a mystery

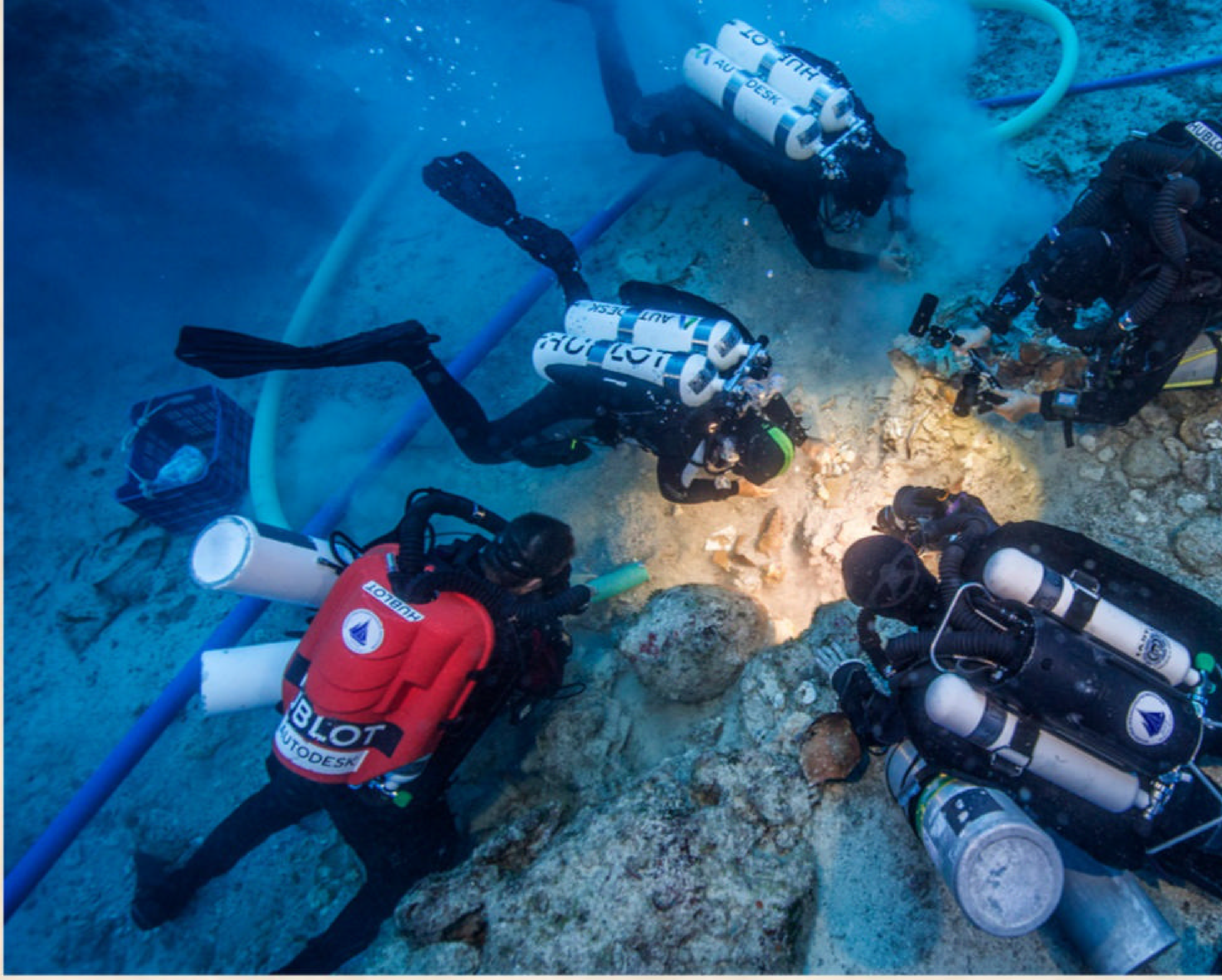
From the 1950s to his death in 1983, English physicist Derek J. de Solla Price carefully studied the fragments of the Antikythera mechanism. Using radiograph X-ray imaging, he examined the subtle details of the device's two main gears. But he also counted an additional 25 gears, making it quite complex. (For comparison, a typical grandfather clock has 11 or 12 gears.) The two largest gears appeared to have 235 teeth and 127 teeth, respectively. Price consulted with mathematician Otto Neugebauer, who identified these teeth counts as relating to the celestial cycles of the Moon.

Isaac Newton reportedly said calculating the motion of the Moon was the only thing that gave him a headache. Indeed, Luna's movement is extremely complicated. The ancient Greeks, as well as many other cultures, used the phases of the Moon to set their calendars. This lunar cycle — lasting from Full Moon to Full Moon — also served as the basis for many religious and ceremonial events. But the Sun was used to determine the calendar year, and breaking a roughly 365-day year into 12 lunar cycles spread over some 354 days represented a real challenge.

The Moon's orbit around the Earth can be measured two different ways. The Moon moves

Although now thought to have tracked the heavens and kept time, the interlocking gears of the Antikythera mechanism perplexed researchers for nearly a century. NATIONAL ARCHAEOLOGICAL MUSEUM, ATHENS/ANTIKYTHERA MECHANISM RESEARCH PROJECT/KOSTAS XENIKAKIS

Discovered more than 100 years ago, the Antikythera wreck continues to intrigue researchers. Modern excavations, like the one seen here, are still uncovering new artifacts, including the skeletal human remains. BOTH UNDERWATER IMAGES: BRETT SEYMOUR/EUA/WHOI/ARGO



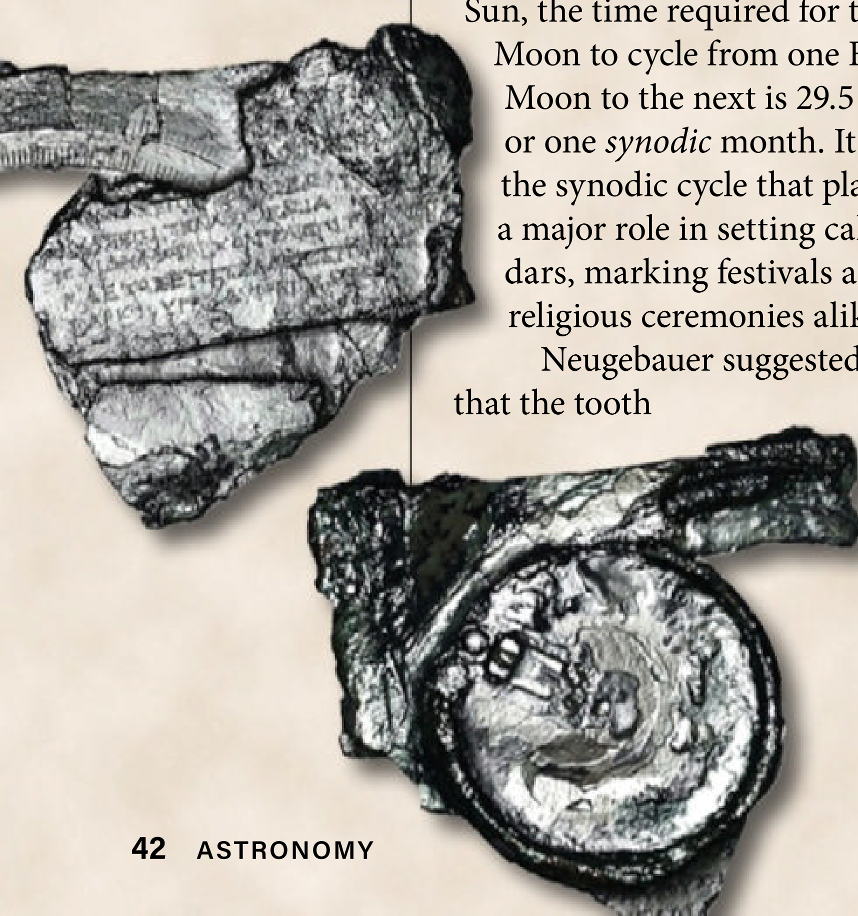
against the backdrop of stars along the path of the ecliptic (the plane of the solar system). The time it takes the Moon to make one full circuit, returning to the same set of stars where it previously appeared, takes 27.3 days. This is known as the *sidereal* month. But due to the simultaneous motion of Earth around the Sun, the time required for the Moon to cycle from one Full Moon to the next is 29.5 days, or one *synodic* month. It is the synodic cycle that played a major role in setting calendars, marking festivals and religious ceremonies alike.

Neugebauer suggested that the tooth count on the two large gears could be related to these well-known long-term cycles of the Moon. The 235-toothed gear appeared to precisely match up with the 235-month (19-year) Metonic cycle of synodic months. This cycle dates back to hundreds of years before the rise of Greek culture, when Babylonian astronomers realized the same phases of the Moon will reoccur on the same dates of the solar year against the same backdrops of stars once every 19 years. This knowledge became vital to keeping the lunar calendar in sync with the solar year.

Trying to perfectly fit 12 synodic lunar months into a solar year is impossible, however. A dozen synodic months adds up to 354 days, which is 11 days short of the roughly 365-day solar year. A strictly lunar calendar would very quickly fall out of step with the seasons. But since the 19-year Metonic cycle contains almost exactly 235 synodic months, it allows celestial trackers to align these two very important ways of measuring time. In other words, the 235-tooth gear could have been used to precisely track the Metonic cycle.

But the 127-tooth gear still presented a mystery — that is, until Price realized that 127 multiplied by two is 254, another number related to the Moon. In the 19-year Metonic cycle, there are 235 synodic lunar months, but 254 sidereal lunar months. Therefore, they concluded, the Antikythera mechanism was likely used to track both the phases and the orbit of the Moon.

Price also examined the device's front plate. With only a small portion of the dial intact, he counted what visible markings he could on the circular scale. He found the inner scale appeared to have 12 divisions, as well the Greek word for "claw," a possible reference to the constellation Scorpio. Other letters, Price



Treasures speckle the shipwreck

THE ANTIKYTHERA MECHANISM is far from the only precious artifact found at the site of an ancient shipwreck that occurred off the coast of a small Greek island some 2,000 years ago. In addition to skeletal human remains, researchers have uncovered remnants of dozens of bronze and marble statues, as well as personal belongings such as gold earrings, silver coins, ornate glassware, pottery, and jewelry.

As part of the Return to Antikythera Expedition in 2017, for example, experts from the Greek Ephorate of Underwater Antiquities and Lund University in Sweden spent more than half a month exploring the underwater archaeological site. Of their many finds was the bronze arm seen in the image above, which presumably broke off a larger statue during the initial shipwreck. After being submerged in salty seawater for some two millennia, the disembodied arm is unsurprisingly rusted, but it's also still in relatively good shape.

Although researchers excavated the bronze arm, they suspect many more artifacts like it are still buried beneath boulders on the seafloor. Only time will tell what other treasures are patiently waiting in those watery depths. *—Jake Parks*

found, suggested the scale was also inscribed with the Greek word for Virgo.

The outer portion of the scale, on the other hand, was divided into 365 sections. Based on the markings and words Price observed, he speculated the front dial tracked the movement of the Sun. Some have even suggested that there were moving pointers dedicated to the five visible planets, which would make the Antikythera mechanism an orrery or planetarium. Modern reconstructions have often incorporated these ideas with some moderate success.

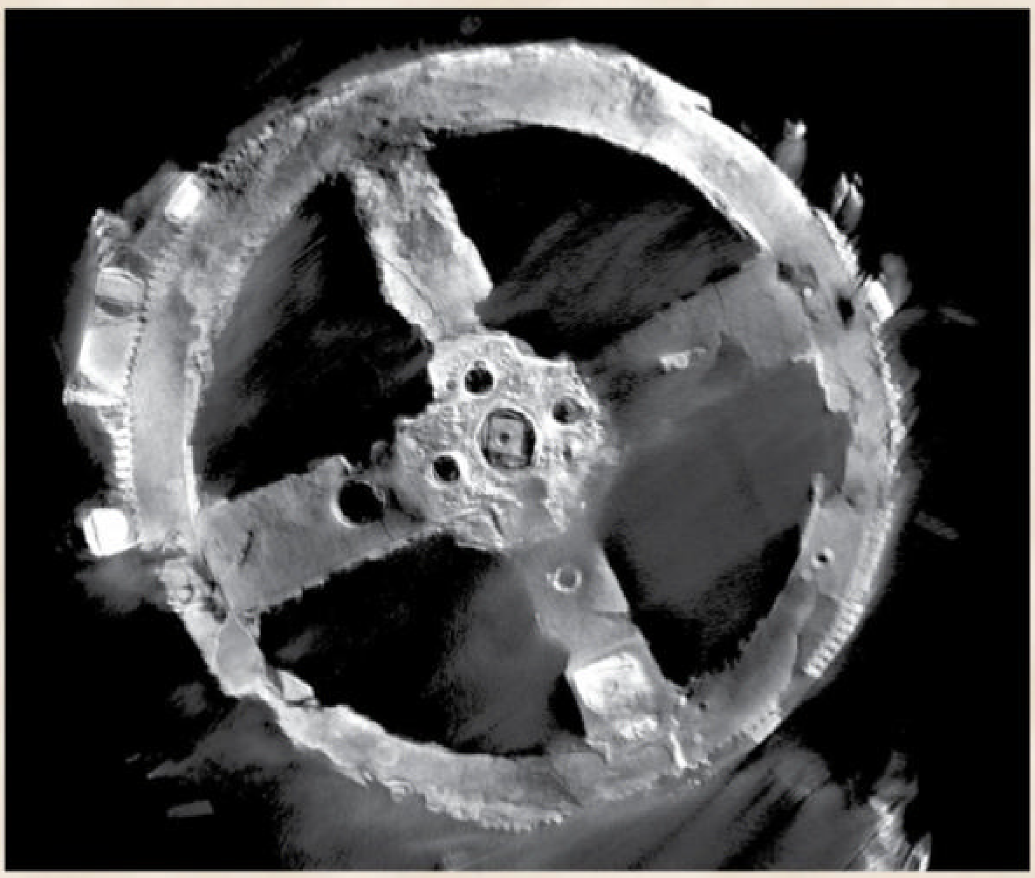
Diving deeper

In 2005, a group of mathematicians, astronomers, and historians in Greece, the U.K., and the U.S. first formed the Antikythera Mechanism Research Project. Their goal was to reexamine the artifact with 21st-century technology. Using a purpose-built 3D X-ray machine, they were able to visually move, layer by layer, through the corroded bronze. The team thinks they've confirmed the 27 gears Price had previously counted, and possibly found evidence for several more.

One smaller gear on the back of the device was particularly puzzling, though. Price had examined this gear and determined it may have had 222 or 223 teeth, and the research team confirmed the latter count. Lo and behold, here was yet another number related to the Moon's motion.

Eclipses, whether lunar or solar, are beautiful and inspiring events. But for the ancients, they were also packed with power and meaning, which is why predicting them was so important. Babylonian astronomers discovered that both lunar and solar eclipses occur in a repeating 18-year pattern. The Saros cycle of eclipses, as it is known, consists of 223 synodic lunar months. So, every 18 years, the Sun and Moon will align again at roughly the same time and position in the sky (though the region on Earth where the eclipse is visible varies).

TOP: These detailed images of various pieces of the Antikythera mechanism were assembled using data collected in 2005. The top row views relied on the technique of polynomial texture mapping (imaging objects under varying lighting conditions to bring out surface features). The bottom row views were created using high-resolution microfocus X-ray computed tomography, or X-ray CT. ANTIKYTHERA MECHANISM RESEARCH PROJECT



RIGHT: X-ray CT allows researchers to take slices of the mechanism's fragments. This view shows the so-called "chariot wheel" gear of fragment A. ANTIKYTHERA MECHANISM RESEARCH PROJECT

Therefore, understanding the Saros cycle was a powerful tool for presaging future eclipses. The Antikythera mechanism, it seems, was an analog computer designed to perform exactly this task.

The ancient eclipse calculator was encased front and back with bronze plates which were inscribed with Greek letters and what appeared to be curved scales. However, corrosion made early attempts to decipher the markings difficult. Price was more successful, finding the back plate covered in what appeared to be instructions for how to use it. He also suspected the incised lines represented scales to provide output information as the gears were turned. But due to damage to the back plate, Price was unable to decipher the lines' exact nature or purpose.

In 2005, the lead researcher of the Antikythera Mechanism Research Project, Tony Freeth of University College, London, took a crack at the problem — and it relied on a small piece dubbed fragment F at the National Archaeological Museum in Athens. New 3D images showed that this part made up the lower section of the back plate. Freeth also noted the continuation of curved lines, which were part of a larger spiral, as well as additional inscriptions. With intense effort, he was able to identify markings that referred to the Moon and the Sun, and the Greek symbol meaning "hour." The spiral dial was used to predict solar and lunar eclipses. The Antikythera mechanism's gears drove a pointer that would tell the user the date and even the time of upcoming eclipses.

Based on what Price found before his death in 1983, he had declared that the Antikythera mechanism was the world's first analog computer. At that point, he lacked a lot of evidence to back up the claim. But thanks to the intense efforts of the Antikythera Mechanism Research Project team, as well as Freeth's relentless detective work, it's now clear that Price had it right all along.

Uncertain origins

While we now have a general understanding of how this ingenious device worked, who made it and how it came to be aboard that doomed Roman cargo ship remains more mysterious — although we do have some hints.

In 1976, explorer and diver Jacques Cousteau reexamined the Antikythera site. He and his crew made many discoveries, providing clues to the origins and date of the ship that carried the mechanism. Cousteau recovered a handful of silver and bronze coins from Pergamon in Asia Minor that dated back to 65 to 50 B.C.

Wine jars known as amphora were also recovered, and the style of the jars indicated that they were made in Rhodes and on the island of Kos. The amphoras dated back to around 70 to 60 B.C. Based partly on this evidence, many researchers assume this cargo ship was carrying treasure that originated in the eastern provinces of the Roman Empire. But that still doesn't shed light on whether the Antikythera mechanism was captured loot or a purchase for a wealthy Roman intellectual.

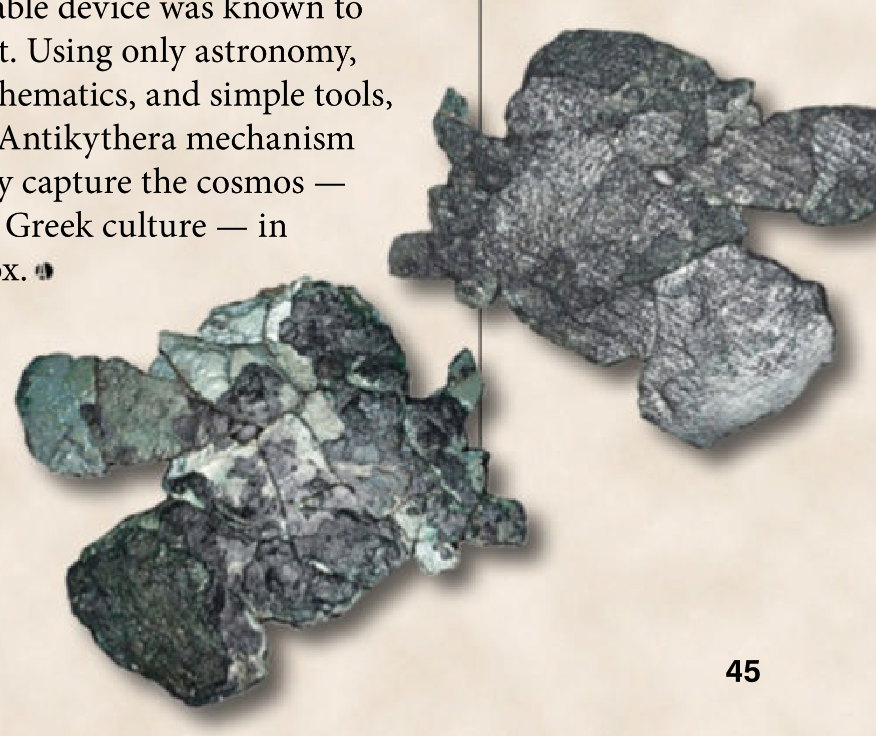
This exploded view shows what the Antikythera mechanism might have looked like. Here, the front plate (left) includes zodiac and calendar dials, as well as seven pointers. The back plate (right) has spiral scales for displaying solar and lunar eclipses and more. A new reconstructed view of the device featuring a revised front plate is expected to be published soon.

The individual who commissioned the mechanism will likely always remain a mystery, as will the craftsman who built it. But there are clues inscribed on the bronze plates that can help reveal the society that devised such a device. In the ancient world, calendars were far from uniform. And based on the names of months and festival designations inscribed on its bronze plates and dials, the Antikythera mechanism likely was born somewhere in northwest Greece.

In this region was the island of Rhodes — home to the astronomer Hipparcus (190–120 B.C.) and his successor Posidonis (135–51 B.C.) at the time of their deaths. The Antikythera mechanism was likely made around the time that Posidonis was teaching and traveling across the Roman world. The Roman senator and contemporary of Julius Caesar, Cicero (106–43 B.C.), even once mentioned the home of a prominent Roman containing what may have been an orrery or planetarium device made by Posidonis. This brief allusion tells us that the Antikythera mechanism was perhaps just one example of many similar devices that existed throughout the ancient world at the time.

For example, at the base of the ancient Acropolis in Athens, Greece, stands the Tower of the Winds. Constructed at about the same time as the Antikythera mechanism, this tower served both meteorological and timekeeping functions. And to do that, it relied on sundials, wind vanes, and even a geared water clock. The first-century Greek inventor Hero of Alexandria developed even more complicated devices than the Tower of Winds, too, including steam engines, the first vending machine, a wind-powered organ, automatic doors, and much more. The Greek and Roman world was alive with ideas, inventions, and creativity at this point in history. Although the Antikythera mechanism has long been considered an advanced anomaly, in fact, it was part of a thriving tradition of innovation.

The Antikythera mechanism could calculate 42 separate calendar functions, predict the motion of the Moon, the positions of planets, and the timing of lunar and solar eclipses. It helped track religious ceremonies, festivals, and the Greek Panhellenic games, as well as other sporting events. And it did this all roughly 1,500 years before another comparable device was known to exist. Using only astronomy, mathematics, and simple tools, the Antikythera mechanism truly capture the cosmos — and Greek culture — in a box.



Raymond Shubinski *is a contributing editor of* Astronomy who finds ancient astronomical devices fascinating.

The Last Quarter Moon features the crater Copernicus and its rays, as well as stark shadows along the terminator. These features can be enhanced with colored filters.
NASA'S SCIENTIFIC VISUALIZATION STUDIO

A FILTER FOR EVERY PHASE

The right filter can reduce glare, increase contrast, and make the Moon's features pop. **BY ROBERT A. GARFINKLE**

THE MOON IS AN OBVIOUS TARGET for the beginning observer. It's easy to find. Its mountains, impact craters, and rays of debris are spectacular. And, above all, it's bright.

In fact, you will learn very quickly that it can be painfully bright in any telescope with an aperture larger than about 3 inches, whenever the Moon is more than half Full. From our vantage point during these phases — First Quarter to Third Quarter — the Sun is shining more directly overhead, and, therefore, more brightly on the Moon's surface.

To dim such an overpowering Moon, we can use several types of eyepiece filters, including neutral-density filters and polarizing filters.

But perhaps the most useful are colored filters, made of glass coated in gelatin-dye. At first glance, adding a color tint to your view of the Moon may not seem like an improvement. But colored filters can overcome image deterioration caused by the properties of light. In particular, they can enhance lunar

KNOW BEFORE YOU BUY

Colored filters useful for observing the Moon are sometimes sold as "Moon filters" or "planetary filters." The housings for these filters are threaded in order to screw into the field end of eyepieces. You need to buy them in the correct size for your eyepiece barrel size (0.965, 1.25, or 2 inches), not by focal length. Be sure that the filters you purchase are made of optical quality glass and not plastic. Plastic filters may distort your view and scratch more easily than glass filters.

Pictured is a sample of eyepiece filters and a Lumicon 5-filter holder. The tube on the left is a Meade polarizer. The dark filter below the polarizer is a no. 47 violet filter. The filter labelled "Moon" is a neutral-density filter. *— R.A.G.*

details that are difficult to pick out in white light, and improve the subtle differences between adjoining areas.

Colored filters reduce irradiation, which is when the edges of bright areas on a celestial body encroach upon darker areas, distorting the boundary between them. This can blur the edges of lunar shadows, which are especially prominent along the terminator — the line dividing the lit area of the Moon from the unlit portion. Some filters sharpen shadow boundaries, making them stand out and giving greater contrast to your entire view.

PICK YOUR FILTER

Wratten filter number	Color (alternate designations)	Transmission percentage	Filter factor for color photography	Remarks
8	Yellow	83	2	Blocks ultraviolet, violet, and blue
11	Yellow-green (light-yellow)	78	4	Blocks deep-blue, violet, and ultraviolet; partly blocks red and orange
12	Yellow (deep-yellow)	74	2	Blocks ultraviolet, violet, blue, and portions of green
15	Deep-yellow	66	2.5	Blocks ultraviolet, violet, blue, and portions of green
21	Orange	46	4	Blocks ultraviolet, violet, blue, and portions of green (below 555 nanometers)
23A	Light-red	25	6.4	Similar results to No. 21 (orange). Blocks ultraviolet, blue, and green; transmits infrared, red, and orange (above 580 nm); combine with No. 58 to photograph the Moon in daylight and underexpose by one stop
25	Red	14	8	Transmits infrared, red, and orange. Pair it with a polarizer to photograph the Moon in daylight and underexpose by one stop
38A	Deep-blue	17	8	Of little value in lunar observing with very little improvement in contrast. Shadow edges remain fuzzy. Combine with other filters for different effects. Blocks green, red, and ultraviolet
47	Violet (blue, deep-blue)	3	6	Transmits blue, violet, and infrared (above 760 nm); use to observe lunar rays and bright spots
56	Light-green	53	6.4	Gives a very slight enhancement in contrast. Kodak has discontinued this color, but it can still be found in eyepieces. Transmission characteristics are similar to No. 58
58	Green	24	8	Transmits green (505–560 nm) and infrared (above 725 nm)
80A	Medium-blue (pale-blue)	30	4	Of little use in black-and-white; slight absorption of red, yellow, and green
82A	Very light-blue (pale-blue)	73	1.2	Of little use in black-and-white; slight absorption of red, yellow, and green
96	Neutral density (gray, density 0.90)	13	8	Absorbs equal amounts of light in all wavelengths; does not add tint
—	Polarizing (gray to almost black)	Variable	Variable	Polarizes light to reduce intensity (glare) in 3-inch or larger telescopes during First to Last Quarter; use to observe or photograph the Moon in daylight

This reference table lists common filters used for lunar observations. The transmission percentage is how much light passes through it. The filter factor is the factor by which light is reduced. For each factor of 2, an increase in exposure by one stop is required. For instance, a filter factor of 8 requires an exposure increase of three stops.

Colored filters can also help overcome the effects of hue contrast, which is the blurring of shades of colors at their boundaries. Although most of the lunar surface appears gray, there is a vast spectrum of grayness, in subtle hues spanning white to black. And colored filters can reveal them.

Kodak history

The numbering system generally used today for colored filters for eyepieces and cameras was developed in 1906 and 1907 by Charles Edward Kenneth Mees, while he was the chief scientist and managing director of the Wratten and Wainwright Company in Croydon, England. In 1912, George Eastman purchased the company and brought Mees to Eastman Kodak to establish a research and development laboratory. The identifying number assigned to these filters is still called the Wratten number, though some manufacturers use different color names for certain filter numbers.

Mees originally designed his filters for photographic work, but they are also very useful for visual lunar observing. Usually only a single filter is used at a time, but sometimes I will combine two filters of varying shades of yellows and blues to enhance the contrast between features. Stacking filters, however, also decreases the intensity of the light transmitted to your eye, thereby dimming your overall view. Experiment with colored filters and discover what combination works best for you during different lunar phases.

A colorful toolkit

In my opinion, the three most versatile filters for enhancing lunar observing are No. 80A (labeled medium-blue under the Kodak Wratten system), No. 12 (yellow or deep-yellow), and No. 15 (deep-yellow). A No. 80A reduces some glare, and a No. 12 or No. 15 both enhance contrast while reducing glare. These three color filters are probably the most versatile filters for enhancing lunar observing.

Also beneficial are the No. 8 (yellow), No. 11 (yellow-green), and again the No. 12, which all help to cancel the bluish fringes caused by chromatic aberration in two-element and low-quality refractors while simultaneously enhancing lunar surface detail.

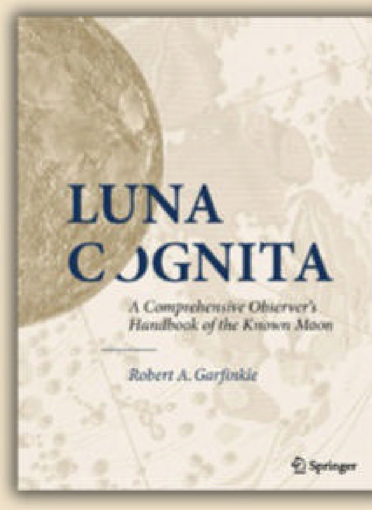
In general, the lighter-color filters are

AN UNDERAPPRECIATED GEM

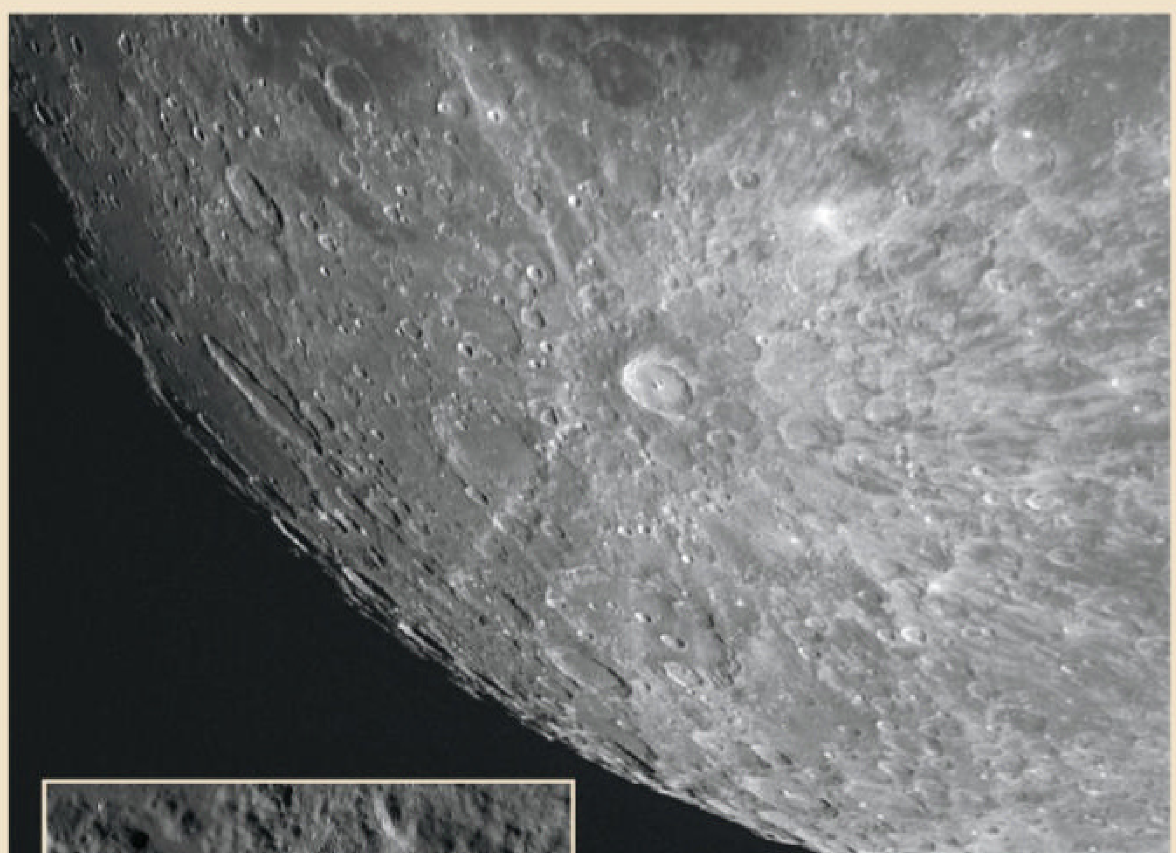
I discovered just how useful the No. 47 (violet) filter can be for lunar observing by accident. In the dark one night years ago, I installed this filter into the base of an eyepiece. At first, I was startled by the view. Then I marveled that I had never heard anyone mention using this filter for lunar observation. In fact, I have yet to find any mention of this in other lunar observers' guidebooks, books on astronomy filters, or filter catalogs. None of those sources say anything positive about the use of the No. 47 filter for lunar work — and at least one advises against it.

True, this filter gives lunar features blue to purplish hues and reduces the overall contrast between gray features and shadows. Shadow edges are not as sharp as with the yellow and orange shades. But the small lit craters are even more noticeable because there is greater contrast between the features that appear white and those that become blue. The rays appear almost white and are therefore easier to observe against the blue and purple background.

In this filter, rays stand out like 3D images. Shortly after First Quarter, the rays emanating from the northeastern crater Thales become hard to detect in white light. But they are very noticeable through a violet filter. I find that many of the branches of the extensive Tycho ray system are easier to detect in violet than when observed at Full Moon through a polarizing filter. I have also noticed that, because a No. 47 filter allows only about 3 percent of the light to pass through it, I do not have to use a polarizing filter to reduce the brightness of a gibbous or Full Moon. *—R.A.G.*



This article has been adapted from the author's new three-volume lunar observers' handbook, *Luna Cognita: A Comprehensive Observer's Handbook of the Known Moon*. Copyright 2020 by the author and reprinted by permission of Springer.



ABOVE: Tycho is a young impact crater in the southern lunar highlands and sports one of the Moon's most prominent ray systems. JOHN CHUMACK

LEFT: Thales Crater lies just west of the larger crater, Strabo. Thales H is visible in the southwest corner of this image taken by NASA's Lunar Reconnaissance Orbiter (LRO). NASA/GSFC/ARIZONA STATE UNIVERSITY

This series of images taken through RGB filters shows how colored filters can alter the contrast between different features on the Moon. A red filter (above left) reduces the contrast of lunar features but can be useful when imaging the Moon during the day. A green filter (above right) provides a slight boost in contrast.

POLARIZING TIPS

You can buy single polarizing filters and stack them up under the eyepiece, crossing their polarization at right angles to darken the view. But I prefer to use an adjustable polarizing filter system that contains two polarizing filters in a holder (see page 48) that slides into the focuser. The eyepiece barrel slips into the polarizer. The polarizing system allows you to vary how much light will pass through by sliding a lever or knob on the housing, allowing from 3 percent to about 50 percent of the Moon's light to pass through.

One annoying problem of using a polarizing system is having to refocus the telescope when installing or removing one. This is because the polarizing system moves the eyepiece away from its normal spacing in the eyepiece holder where you have focused the image. When you remove the filter, the previous spacing is restored and you have to restore your original focus.

Even with a polarizing filter in place, plan to make your lunar-observing session a short one to avoid hurting your eyes. After just a short session of looking at the Moon during the bright phases, I have looked away from the telescope and seen everything in a blurry distorted red shade. Always use care when looking at the bright Moon (between First Quarter and Third Quarter phases) through any telescope. *—R.A.G.*

best to use between New Moon and around First Quarter, and between Third Quarter and the last days of a waning Moon. When the Moon is more than half Full, you can dim its brightness with a Moon filter, a polarizing filter, or the No. 47 (violet) filter.

The following is a list of some of the color eyepiece filters that are commonly sold for lunar observing:

No. 8 (yellow) gives sharp contrast between shadows and illuminated surfaces. Small features stand out, such as the individual peaks in Theophilus and shallow rilles that are not visible in a No. 21 (orange) filter.

No. 11 (yellow-green) has a slight improvement in contrast over the No. 8 (yellow). Either filter is good for observing at low solar illumination angles near the terminator. It also aids in locating lunar domes.

No. 12 (yellow or deep-yellow) improves hue contrast and sharpens shadow edges. It's great for observing small cone craters and maria wrinkle ridges that are lit by low solar illumination, and helps in locating domes. It's also better than lighter yellow filters like No. 8 and No. 11 at bringing out fine details in rays, such as the Messier A comet tail rays in Mare Fecunditatis.

No. 15 (deep-yellow) is slightly darker with similar observing properties as No. 12, adding finer details to images.

No. 21 (orange) sharpens hue contrasts at shadow boundaries and reduces irradiation. This filter helps to make the crater rays more visible. The Moon turns a deep orange color, which takes some time to get used to. It also slightly darkens the Moon overall.

No. 25 (red) darkens the entire Moon and provides little visual improvement for lunar observing. Shadows are not as sharp as with green and yellow filters. The Moon's terminator fades to black without a clearly defined edge to shadows. When used in combination with a polarizer, this filter enhances artistic black-and-white photographs of the Moon in daylight by dimming the

Under Kodak's ownership, the Wratten system of gelatin-dye colored filters became a mainstay of photography and astronomical observing. MEKONNEN WOLDAY / KOMMANDØR CHR. CHRISTENSENS HVALFANGSTMUSEUM. CC BY SA 2.0

A blue filter (above left) can bring out different shades of gray due to variations in chemical composition, as well as emphasize bright crater rays. The false-color image (above right) combines the other three (see page 50) and shows the different features each channel highlights. FERNANDO MENEZES

blue sky. It is used mainly for viewing the planets.

No. 47 (violet) is called deep-blue by Kodak, but sold and advertised as violet, blue, or deep-blue for viewing Venus, Saturn's ring structure, and clouds over the Martian poles. This filter darkens a lunar view, making it easier to observe the ray systems during the bright lunar phases. While this filter is too dark for use during the crescent phases, it is outstanding for the phases between First and Last quarters.

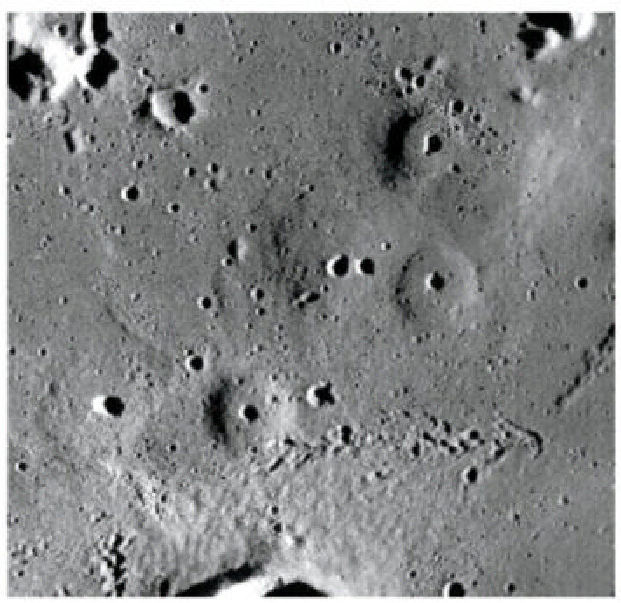
No. 58 (green) aides in observing thin shadows, such as crater wall terrace valleys, and very sharp shadow boundaries. It brings out subtleties in shading of mare surfaces. One can also pick out finer details with this filter than with no filter at all.

No. 80A (medium-blue) reduces glare and enhances contrast between areas of varying grayness.

No. 82A (very pale-blue) also helps to reduce chromatic aberration in low-quality refractors. The Moon appears gray in a No. 82A. However, shadow edges are not as crisp as with orange and yellow filters.

Neutral options

No. 96 (neutral-density; also sold as



The Hortensius Domes, located near their eponymous crater in Mare Insularum and seen here in an image taken by LRO, are examples of lunar shield volcanoes. The relatively shallow slopes of lunar domes can make them tricky to spot, but a yellow filter can help by increasing the contrast of your view. NASA/GSFC/ARIZONA STATE UNIVERSITY

"Moon filters") reduces the brightness of the Moon evenly across the entire spectrum without adding a color tint. Depending on the density, these filters block out a fixed percentage of the light, thereby reducing some of the glare without introducing false colors. They come in a wide range of densities, but usually you will find eyepiece filters having a density of 0.90 with a transmission rating of 13 percent. (A warning: Never use photographic neutral-density eyepiece filters for viewing the Sun. Instead, use a properly designed solar filter that fits over the aperture of your telescope or camera.)

Polarizing eyepiece filters are designed to reduce the lunar glare and darken the background sky, thereby making it easier to view the Moon from First through Third Quarter. Your view of the Moon through a polarizing filter will be in darkening shades of gray to almost black. These filters are also great for observing the Moon at First or Third Quarters in daylight because sky light is most polarized 90° from the Sun.

The Moon may be the easiest object to find in the night sky, but observing it is endlessly rewarding. This list of filters and ways to use them is far from exhaustive. Never be afraid to experiment with different combinations of color filters and find new ways to enhance your views and photographs of our nearest celestial neighbor.

Robert A. Garfinkle, *fellow of the Royal Astronomical Society, is an independent historian of the history of astronomy and the author of the books* Star-Hopping: Your Visa to Viewing the Universe *(Cambridge University Press, 1994) and* Luna Cognita *(Springer, 2020).*

NGC 2237-9
ROSETTE NEBULA

This bicolor image of the Rosette Nebula (NGC 2237-9) using Astrodon Hydrogen-alpha and Oxygen-III filters required six hours of exposures through a Starlight Xpress H694 monochrome camera attached to a William Optics GT81 refractor on an iOptron CEM60 mount.

Grab-and-go

astroimaging

Life's too short to spend a lot of valuable time setting up and aligning.

TEXT AND IMAGES BY CHRIS GRIMMER

With more of us living in cities and urban environments, the problem of light pollution is all too familiar. Even those lucky enough to live outside large metropolises don't escape untouched, because the sky near the horizon is often lost to sky glow. This leaves astroimagers with a choice to make: Invest in a fixed setup with narrowband or light pollution filters, or make the best of a lightweight, portable setup and head to dark-sky sites.

In my case, the choice was made for me. I live in the center of a city, so a permanent setup was neither a viable nor secure option.

But how far can one go in this hobby with a kit light enough to be transported and built on location, without assembly consuming the entire evening? After all, everything beginning imagers hear or read promotes the idea that aperture is king and that the longer the exposure time, the better your results. And it's well known that a solid mount is a minimum requirement.

I didn't think that any of those principles were compatible with portability. But eventually, I realized that with the technology now available, you can go far in this hobby with just a little extra work and commitment.

The author stands next to one of his portable astroimaging setups.

Equipment considerations

I first became obsessed with choosing the correct mount. It was difficult to find strong equipment that was also lightweight. But because the mount is critical, I needed to get this right. After a considerable amount of research, I settled on a center-balanced equatorial mount (CEM). The deciding factor was its promise of a high weight capacity from a mount that itself weighed significantly less than a standard German equatorial mount.

Over the years, I've experimented with numerous setups, looking for the perfect one. After a few years of imaging large nebulae with a 3.2-inch refractor, I purchased a 10-inch Ritchey-Chrétien (RC) reflector to use as a portable imaging setup to shoot galaxies. It weighed in at 55 pounds (25 kilograms), but my mount easily handled the weight. (I, on the other hand, just barely managed the hefty telescope.)

I had other issues as well. The first was collimation; the process of transporting the scope ensured its optics needed realigning prior to each setup.

Also, a cool-down time in excess of two hours was required. Suddenly, half my night was spent setting up or just waiting around. I learned an expensive lesson: An RC is not a portable imaging scope.

Until recently, I had been using a monochrome CCD camera, filter wheel, electronic focuser, and guide camera on my 3.2-inch refractor. The entire system has a combined weight just over 13 pounds (6 kg). This gave me the portability I needed, while allowing me to capture the long, guided exposures I wanted. I have had great success with this setup and can be up and running within 45 minutes of arriving onsite. The only drawback is that it requires access to AC power. Having access to a roll-off shed at a local observatory has allowed this setup to work well, but on nights when that site wasn't an option, it's quite a limiting factor.

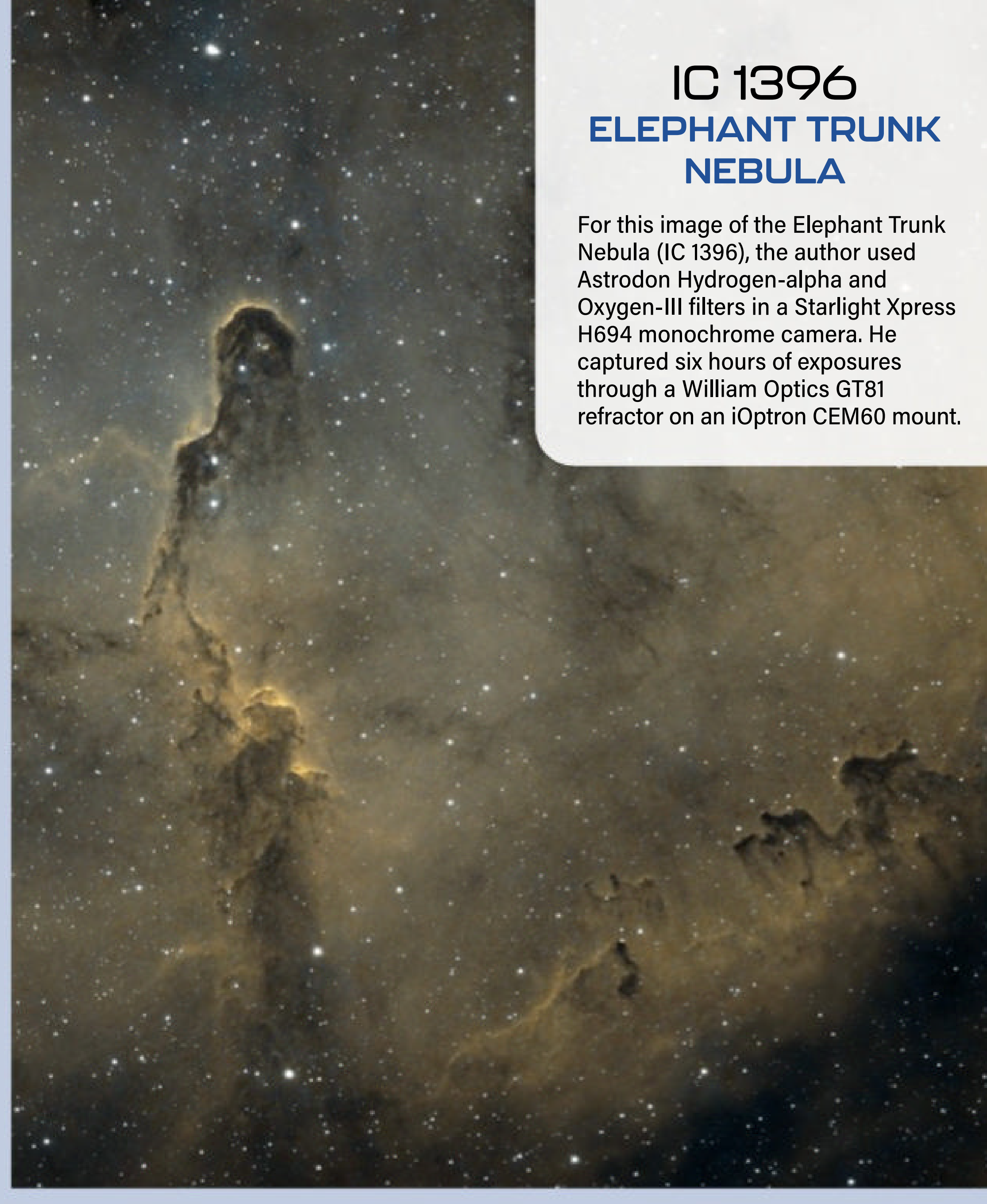
After all my trials, I have settled on an excellent system. Over the last few years, mount technology has come a long way and lightweight "star trackers" have come into their own. These were originally designed to carry a DSLR for wide-field Milky Way photography; however, some can now carry as much as 11 pounds (5 kg). This increased payload, while impressive for a small mount, still falls short for my refractor setup.

To address this, I needed to strip it down and return to basics. The purchase of an adapter allows camera lenses to be connected to a CCD, and removal of the guider led to an extremely light setup that didn't require AC power. Instead, everything runs from a 12-volt battery connected to a multi-USB adapter.

Exposure times

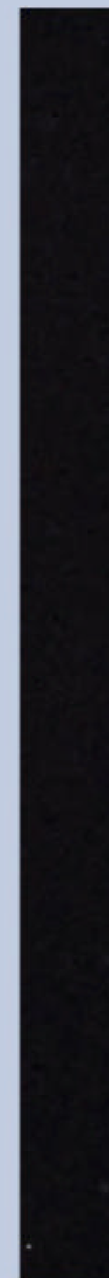
Posts in forums, magazine articles, and comments on social media made it clear to me that better images result from combining longer individual exposures. I wondered how much difference this makes in the real world. Also, what constitutes a "long exposure" for modern cameras?

I know from experience with my own camera that three hours of total exposure time is the minimum



IC 1396
ELEPHANT TRUNK NEBULA

For this image of the Elephant Trunk Nebula (IC 1396), the author used Astrodon Hydrogen-alpha and Oxygen-III filters in a Starlight Xpress H694 monochrome camera. He captured six hours of exposures through a William Optics GT81 refractor on an iOptron CEM60 mount.

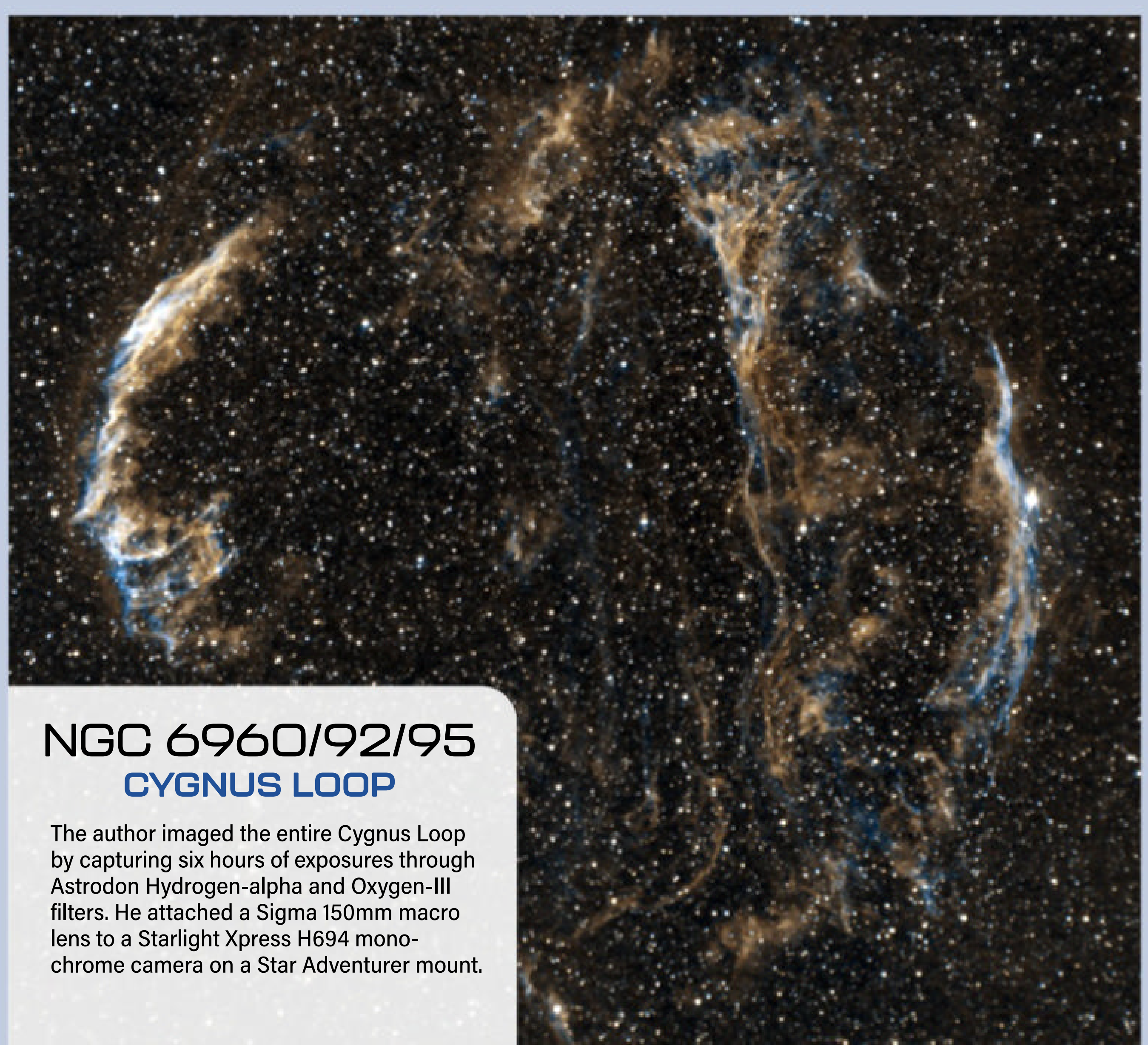


IC 1848
SOUL NEBULA

This Hubble palette image of the Soul Nebula (IC 1848) required Astrodon Hydrogen-alpha, Oxygen-III, and Sulfur-II filters. The nine hours of exposures were captured through a Starlight Xpress H694 monochrome camera attached to a William Optics GT81 refractor on an iOptron CEM60 mount.

M51
WHIRLPOOL GALAXY

For this full-color image of the Whirlpool Galaxy (M51), the author captured six hours of exposures through a 10-inch Astrosib Ritchey-Chrétien reflector. He used a Starlight Xpress H694 monochrome camera with Astrodon filters and mounted everything on an iOptron CEM60 mount.

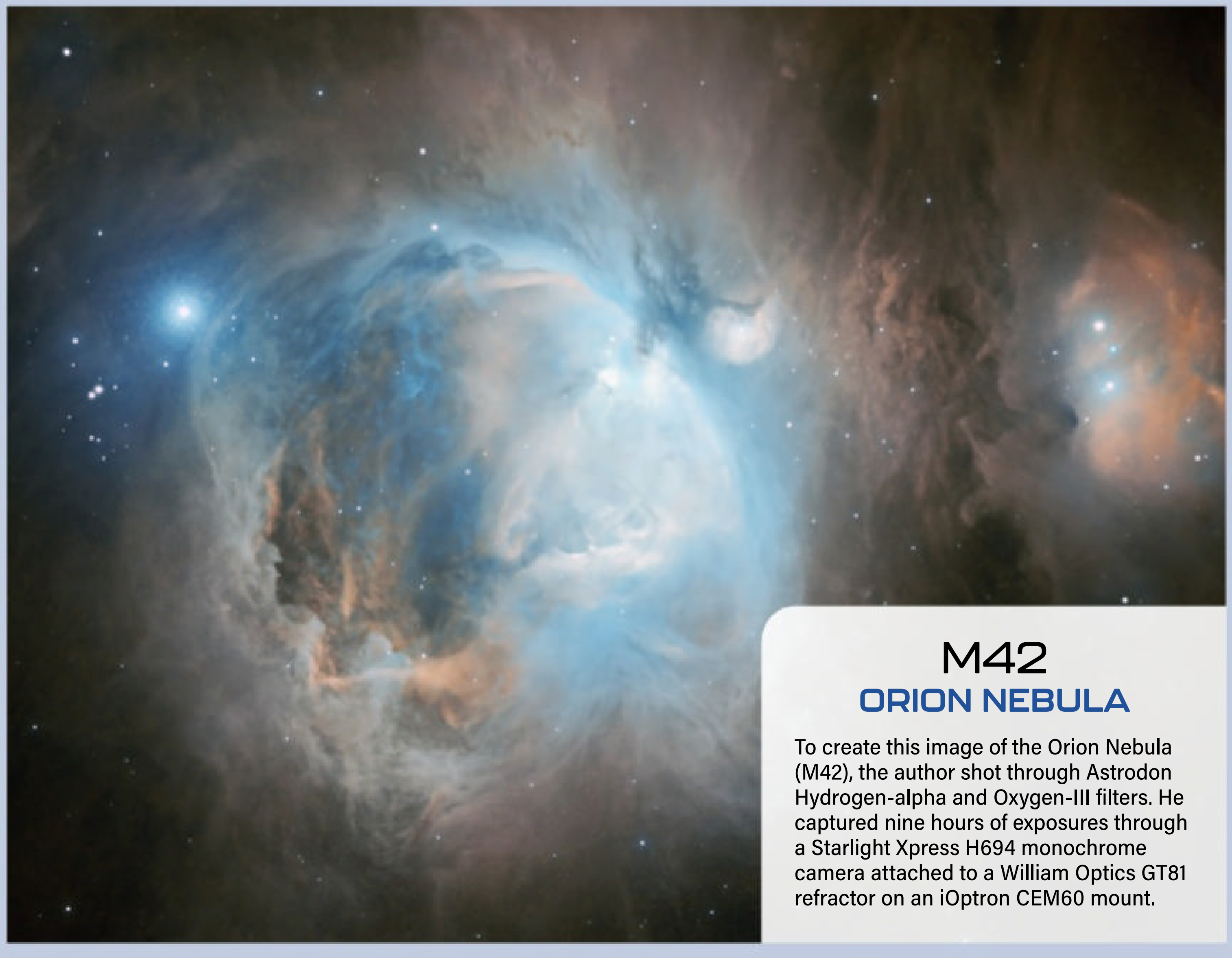


NGC 6960/92/95
CYGNUS LOOP

The author imaged the entire Cygnus Loop by capturing six hours of exposures through Astrodon Hydrogen-alpha and Oxygen-III filters. He attached a Sigma 150mm macro lens to a Starlight Xpress H694 monochrome camera on a Star Adventurer mount.

NGC 6960/92/95
VEIL NEBULA

This two-panel mosaic shows the Veil Nebula (NGC 6960/92/95). The setup used Astrodon Hydrogen-alpha and Oxygen-III filters in a Starlight Xpress H694 monochrome camera attached to a William Optics GT81 refractor on an iOptron CEM60 mount. Exposure time for each panel was six hours.



M42
ORION NEBULA

To create this image of the Orion Nebula (M42), the author shot through Astrodon Hydrogen-alpha and Oxygen-III filters. He captured nine hours of exposures through a Starlight Xpress H694 monochrome camera attached to a William Optics GT81 refractor on an iOptron CEM60 mount.

IC 1396
ELEPHANT TRUNK NEBULA

This image of the Elephant Trunk Nebula required six hours of exposures through Astrodon Hydrogen-alpha and Oxygen-III filters. The author took them by attaching a Sigma 150 mm macro lens to a Starlight Xpress H694 monochrome camera. A Star Adventurer mount carried the equipment.

required for a high-quality result. But I wondered: Does the individual exposure length affect the outcome? For years, I had used 15-minute exposures as my staple, but when I removed the autoguider that I had on previous systems, these were no longer feasible. After a little experimentation, I settled on 60-second exposures. This has proven to be a nice length because I haven't lost many frames due to drive errors.

To say I was pleasantly surprised with the results is an understatement. The shorter exposure length did not impact image quality. All the faint details I was used to seeing were still present once I stacked the images. And the noise levels in the one-minute exposures were also on par with the stacked 15-minute photos I was used to working with.

The one downside to using camera lenses instead of my small refractor is that the lenses' shorter focal lengths result in slightly reduced image sharpness. However, the shorter focal length options have opened a whole new catalog of large targets that I could not image previously.

Success

Experimenting with a portable setup has shown me that no matter where you live, there are always options that don't require you to sacrifice image quality. I now have a full astroimaging setup that fits in a backpack. So even if my mode of transport is a motorbike, I can head to a remote site with full confidence.

The lightweight setup combined with taking shorter exposures suits newer DSLRs and works brilliantly with older CCD sensors and their larger pixels. And the flexibility afforded by the ability to switch between camera lenses opens the sky in a whole new way. Ultimately, this lightweight, portable setup has reenergized me and reawakened my love of the hobby. Here's hoping it will do the same for you.

Chris Grimmer *is an astroimager specializing in deep-sky objects. He is based in Norfolk, U.K.*

Unistellar's new technology will let you see galaxies and nebulae from your backyard. **BY MICHAEL E. BAKICH**

Meet the user-friendly eVscope

AFTER THREE YEARS of development and testing, Unistellar, a company based in Marseilles, France, launched the eVscope's Kickstarter fundraiser October 25, 2017. In just 30 days, the campaign raised $2.2 million with more than 1,600 people pre-ordering an eVscope for $1,299. The campaign and subsequent videos promised a lot. So, naturally, I couldn't wait to try it out.

Unistellar shipped me the eVscope and its tripod in one large box. In it were two smaller packages: One held a well-padded backpack that protected the telescope — a 4.4-inch f/4 reflector with a mirror made of borosilicate-crown, a high-grade glass. The other box contained an aluminum tripod.

Setting up

The first step is to charge the battery of the eVscope. Make sure to do this several hours before your observing session, as Unistellar states that it takes seven hours to fully charge the battery. The company provides an adapter that plugs into any outlet within a range of 100 to 240 volts AC. The other end, which outputs 5.0 volts at 2.4 amps, connects to the bottom of the scope. Inside is a 15,000-milliamp-hour battery, which, the company claims, will run the scope for nine hours. If you aren't sure the battery is full, you can use the scope while it's charging.

Download Unistellar's app from the Google Play Store or the Apple Store. On your phone, select "Settings" and then "Wi-Fi" and connect to evScope network. Its name consists of "eVscope" and six random characters. Once connected, you can move to the next steps.

When outdoors, your first task is to find a viewing location and level the tripod. Unistellar makes this easy by incorporating a bubble level at the top of the tripod. This is also the time to set the tripod's height. Each leg has two locking extenders. I settled on a height where one of the extenders was all the way out. Also at the top of the tripod, you'll find two knurled knobs. Loosen them so you can insert the scope's round bottom into the tripod. Then tighten the screws.

PRODUCT INFORMATION

Unistellar's eVscope
Aperture: 4.4 inches (112 millimeters)
Focal length: 450 mm
Focal ratio: f/4
Power supply: 100-240 volts AC at 50 or 60 Hertz
Wi-Fi frequency: 2.4 Ghz
Comes with: AC adapter, tripod
Price: $2,999
Contact: Unistellar SAS
19 rue Vacon
13001, Marseille, France
No. SIRET: 81233935600022

Turn on the eVscope by pressing the button on its side for one second. In a few more seconds, the light changes from purple to red, and the scope is ready to go.

Focus and alignment

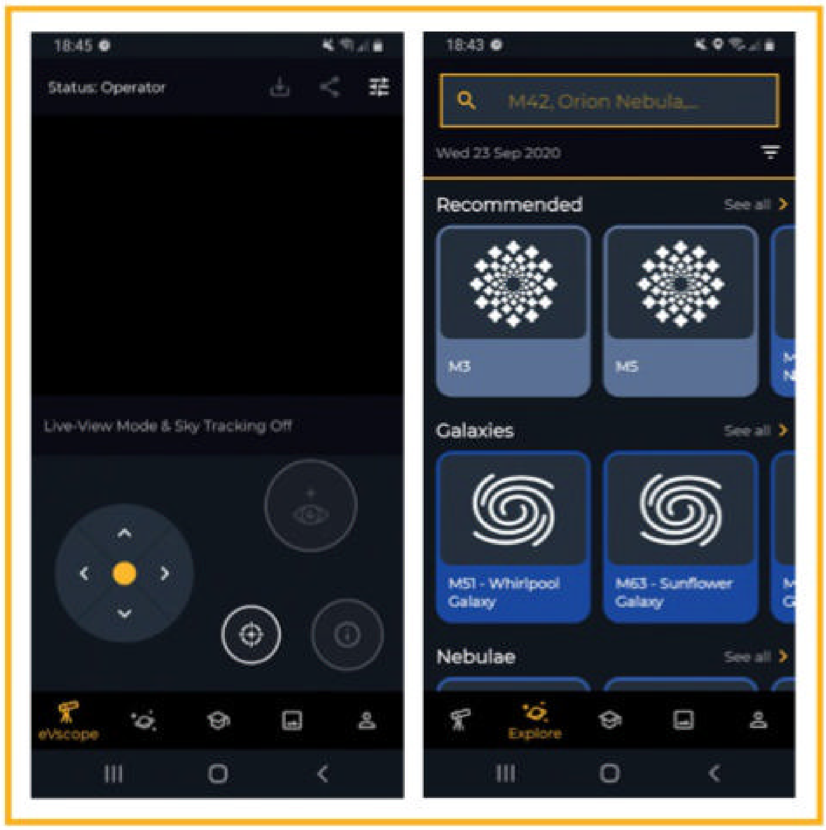
Launch the Unistellar app. Even with my old phone, it booted up and worked flawlessly.

Select the "eVscope" icon at the bottom (the leftmost of the five icons). From your phone, use the arrow buttons to move the scope to roughly 45°. The purpose here is to find some stars that will enable you to focus the scope. If you don't see stars, play with the arrow buttons until you do. You'll also find the large round focus knob at the bottom of the scope. For an initial focus, align the mark on the knob to the top screw. Then, either watching the display on your phone or looking through the eyepiece, adjust the knob to achieve the best focus.

To focus the non-interchangeable eyepiece, turn it clockwise or counterclockwise. Unistellar has built a Bahtinov mask into the main dust cap to help you achieve the best possible focus. First, twist the mask to separate it from the dust cap, and install it the same way you would the cap. Then, touch the "Explore" icon, the one that looks like Saturn with three stars (or moons?) around it. Scroll down to "Stars," and select any bright star. Then hit the "Go to" button.

With the star centered and the Bahtinov mask on, you'll see a pattern (called a diffraction pattern) that looks like an X with a central vertical line through it. Your job is to use the bottom knob to focus until the vertical line cuts through the center of the X. When that's done, remove the mask.

Next, touch the "Automated Alignment" icon to the right of the joystick. It looks like a target. By doing this, you'll engage one of the coolest features of the eVscope. The built-in computer will compare the star field you found to its database. When finished — it takes about 15 seconds — the scope will be aligned to the sky. At this point, you'll see "Sky Tracking On" and you're ready to observe.



▲ The left image is the main screen — the one with the joystick — you'll see on your phone. The right image pops up when you touch the "Explore" icon. COURTESY OF UNISTELLAR

Enhanced viewing

Touch the "Explore" icon at the bottom. You'll find eight rows of objects on the display that the eVscope calculated are visible in your sky: "Recommended," "Galaxies," "Nebulae," "Clusters," "Stars," "Planets," "Transient Events," and "Advanced." You can scroll through each row to choose from 10 objects, or, in the case of the bottom three rows, as many as are visible. Each of the top seven rows has a "See all" option, which lists more. "Galaxies," for example, had 92 entries at one point.

Touching one of the object buttons moves you to another screen. One of its windows shows the object's altitude (in degrees) and azimuth (as a compass point, such as "NNE"). The window below that provides some additional info on the object. There's also the "Go to" button.

When you touch "Go to," the scope moves until your selected object is in the field of view, both through the eyepiece and on your phone. You're in "Live View" mode. Try not to be disappointed by the view. Remember, it's a 4.4-inch scope. In this mode, the icon at the upper right will allow you to adjust "Gain" and "Exposure time." Have some fun playing with these controls. You'll notice that the two sliders below, "Contrast" and "Brightness," are locked.

The telescope's carbon-fiber tube is both lightweight and very strong, giving this model a high-tech appearance.

But the coolest thing happens when you touch the icon that looks like an eye with a star and enter "Enhanced Vision Mode." After a few minutes (it varies depending on your settings), during which the telescope is collecting light from the chosen object, the app will show nebulosity where none was visible before, arms of spiral galaxies where only a hazy core showed, and as many as a dozen times more stars within clusters — all with color.

If you like what you see, touch the "Download" icon at the top to save your image. You can view them later by tapping the "Gallery" icon at the bottom.

When you finish observing, touch "User," and then hit "Park My eVscope" to send the unit to its home position. Replace the caps, and you're done.

Evaluation

Even during Tucson's monsoon season, many nights are clear, so clouds weren't a problem. But, I was testing the eVscope during the height of the West Coast wildfires. There were days that meteorologically were "sunny," but I could not see the Sun. The night sky was just as bleak.

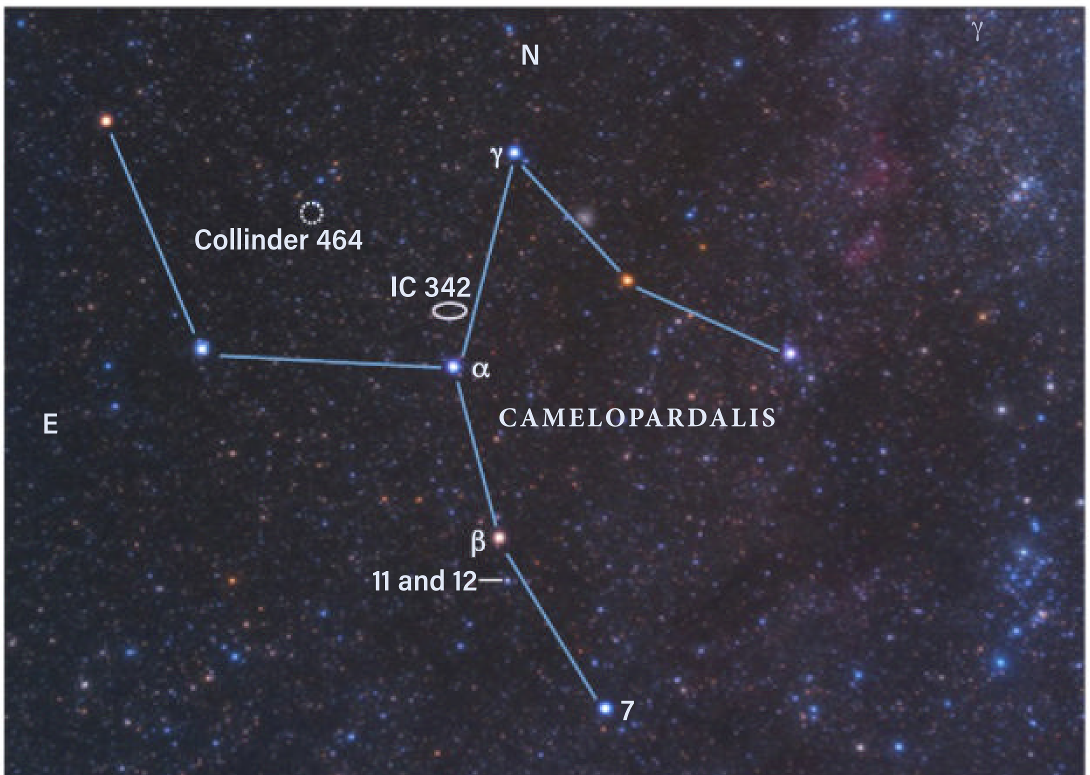
I did, however, enjoy extended views of more than a dozen objects. They included the Dumbbell Nebula (M27), which revealed its characteristic shape, the Hercules Cluster (M13), which filled the eyepiece with sharp points of light, and the Wild Duck Cluster (M11), which abounded with colorful stars. And every object looked much better in Enhanced Vision mode than in Live View.

Unistellar has created a nearly foolproof instrument that even novice skywatchers will have a blast with. And by the time you read this, version 1.1 of the software, which incorporated some requests by users, should be installed. Have fun!

Michael E. Bakich *is a contributing editor of* Astronomy.

Exploring Camelopardalis

This constellation may seem bereft of stars, but, on closer inspection, has some dazzling sights.



Despite appearing devoid of stars to ancient astronomers, Camelopardalis is the 18th-largest constellation in the sky. TONY HALLAS

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

Last month, we visited the constellation Lepus, found south of Orion. This month, we will turn our attention toward the area north of Auriga. This region appears nearly starless even under dark rural skies. Ancient stargazers also thought this section of the sky was empty, so never concocted a constellation there. It wasn't until 1612 that the Dutch-Flemish astronomer Petrus Plancius drew a pattern among those faint points: A giraffe, which he called **Camelopardalis**.

That's right — Camelopardalis is not a camel, despite the misleading name. Translated, the Latin term *Camelopardalis* roughly means "camel leopard," which comes from the way ancient Greeks described giraffes. So, even though they didn't conceive the constellation, in one sense they did give it a name.

While Camelopardalis may not look like much to the unaided eye, it does hold some buried treasure for binocular users. Are you up for a hunt?

The brightest star in the celestial giraffe is 4th-magnitude **Beta (β) Camelopardalis**, found about 15° north of Capella (Alpha [α] Aurigae). Beta Cam is a type G1 yellow supergiant, slightly hotter than our Sun and over six times as massive. It lies 870 light-years from our solar system, roughly the same distance as Rigel (Beta [β] Orionis). Through binoculars, it displays a subtle yellowish tint.

While you are enjoying Beta Cam, take notice of a fainter pair of stars just a degree to the south. Those are **11** and **12 Camelopardalis**. They appear just 3' apart on the sky. Through binoculars, 5th-magnitude 11 Cam shows a delicate blue-white hue, while 6th-magnitude 12 Cam appears orangish. But their numerical affiliation is purely circumstantial, I'm afraid. Astronomers estimate that 11 Cam is 710 light-years from Earth, while 12 Cam is about 10 light-years closer. Although they are relatively near each other in space, they do not form a binary star system.

Given the sparseness of the area, you would hardly expect to find an open star cluster here. And yet there is: **Collinder 464** is a late entry in Per Collinder's 1931 catalog of 471 open clusters. Several clusters Collinder listed were previously included in the Messier and NGC listings, but others were not, including number 464. To find it for yourself, return to Alpha Cam and continue another 8.5° toward Polaris. Keep your eyes peeled for a dozen faint stars loosely gathered across an area measuring about 1° by 2°. The 5th-magnitude star SAO 5455 lies near the center of the cluster. By using a little imagination and borrowing some non-cluster stars in the immediate area, I see Collinder 464 forming the profile of a small dog. In my mind, the dog is facing west, with its legs stretching to the south and tail standing at attention to the east. The stars that mark the tip of the dog's nose, ear, and tail look very slightly orangish, while the others appear white. Years ago, I nicknamed the cluster "Amy" after my toy poodle, who loyally accompanied me on many a night viewing the sky.

Our final stop this month is spiral galaxy **NGC 2403**, one of the brightest galaxies north of the celestial equator that Charles Messier missed. Instead, it was discovered by William Herschel in 1788. Although NGC 2403 lies within the borders of Camelopardalis, it is most easily found by looking about 8° northwest of 3rd-magnitude Muscida (Omicron [o] Ursae Majoris), the star at the tip of the Great Bear's nose. Look for its soft 9th-magnitude glow just north of a rectangle of 8th-magnitude stars. Through my 10x50 binoculars, NGC 2403 displays a dim oval disk skewed northwest-southeast. It lies approximately 10 million light-years away — about the same distance as M81 and M82, which are 14° to its east. Researchers believe that NGC 2403 is likely an outlying member of that galactic group.

We will explore the western portion of Camelopardalis later this fall. But for now, if you have any questions, comments, or suggested targets, I would enjoy hearing from you. Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

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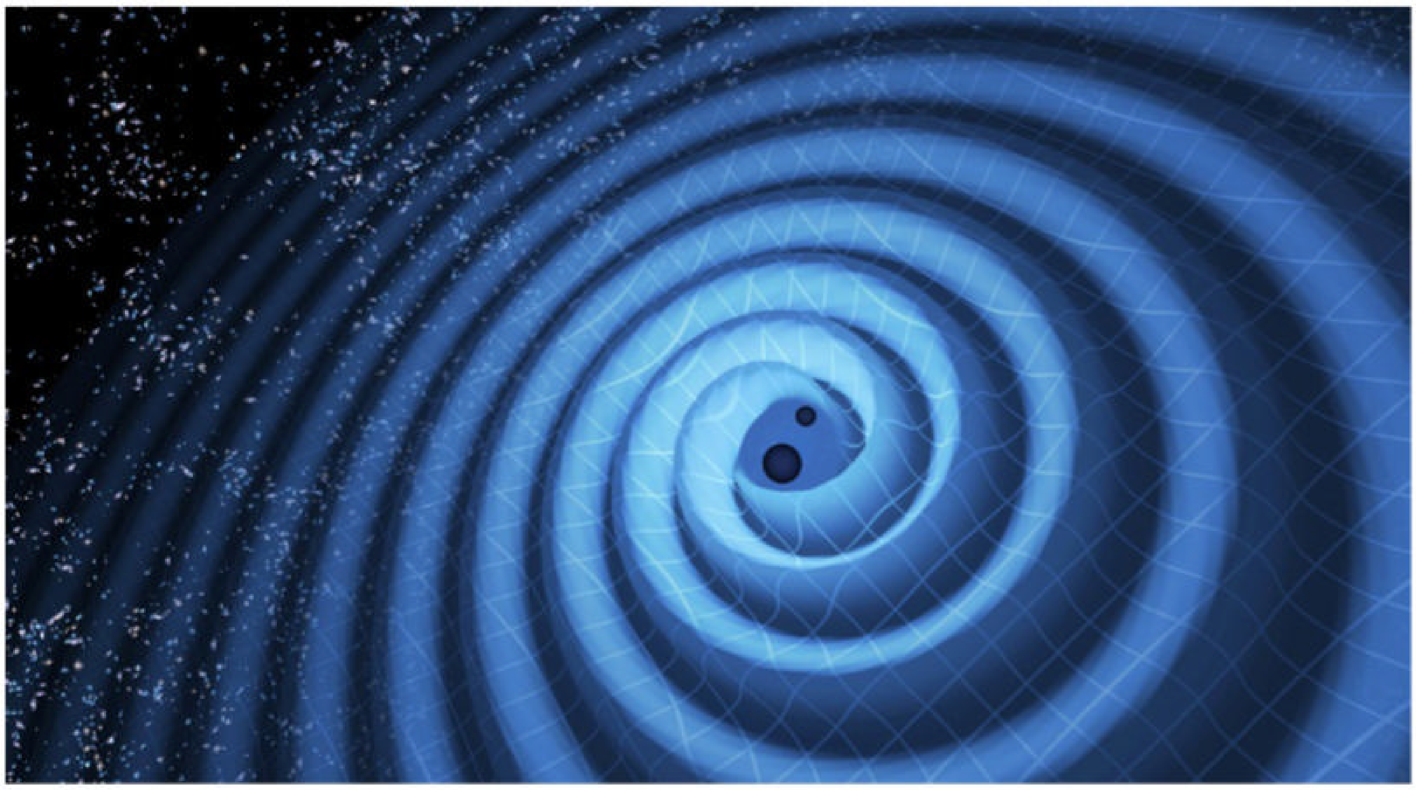


As two black holes spiral toward each other, they create ripples in space-time that propagate out at the speed of light.
LIGO/T. PYLE

Sizing up black hole mergers

Q | HOW DOES LIGO TRANSLATE GRAVITATIONAL-WAVE SIGNALS INTO AN ACCURATE DETERMINATION OF THE DISTANCE AND THE MASSES OF COLLIDING OBJECTS?

Peter Gibbons
Cork, Ireland

A | In 1916, Albert Einstein's theory of general relativity showed that massive objects distort the fabric of space-time. The theory also predicted that violent collisions and other processes could send ripples across the universe in all directions. These gravitational waves, traveling through space at the speed of light, would carry information about their origin.

While Einstein's equations described how a pair of compact objects (like black holes or neutron stars) merged, actually calculating solutions to those equations was impossible for decades. It was only with computer advances in the 1990s that scientists were able to use supercomputers to solve Einstein's field equations, with the first successful simulation of a binary black hole merger available in 2005. Figuring out faster, more efficient, and more accurate ways to characterize measurements of binary black hole and neutron star mergers is a very active area of research for scientists at gravitational wave observatories such as the Laser Interferometer Gravitational-wave Observatory (LIGO), Virgo, and the Kamioka Gravitational Wave Detector.

Gravitational-wave astrophysicists create millions of simulations with these equations to find out how certain combinations of black holes merge and what their gravitational waves would look like if detected. Each of these unique "waveforms" is stored as a kind of template. So, when a new gravitational-wave signal is picked up in a detector, search algorithms can find the template that best fits. Scientists at LIGO essentially work backward from there to figure out which combination of black holes most likely produced the signal. This lets us very quickly identify and verify gravitational-wave events when they happen so we can tell other astronomers around the world to start observing that area of the sky.

Geoffrey Mo
graduate student, LIGO laboratory, MIT, Boston, Massachusetts

Q | IF THE GIANT IMPACT HYPOTHESIS IS CORRECT AND THE MOON IS MADE FROM EARTH AND THEIA (THE MARS-SIZED OBJECT THAT COLLIDED WITH EARTH), WHAT HAPPENED TO THE REST OF THEIA AFTER THE COLLISION?

Steven Peckham
Portsmouth, Rhode Island

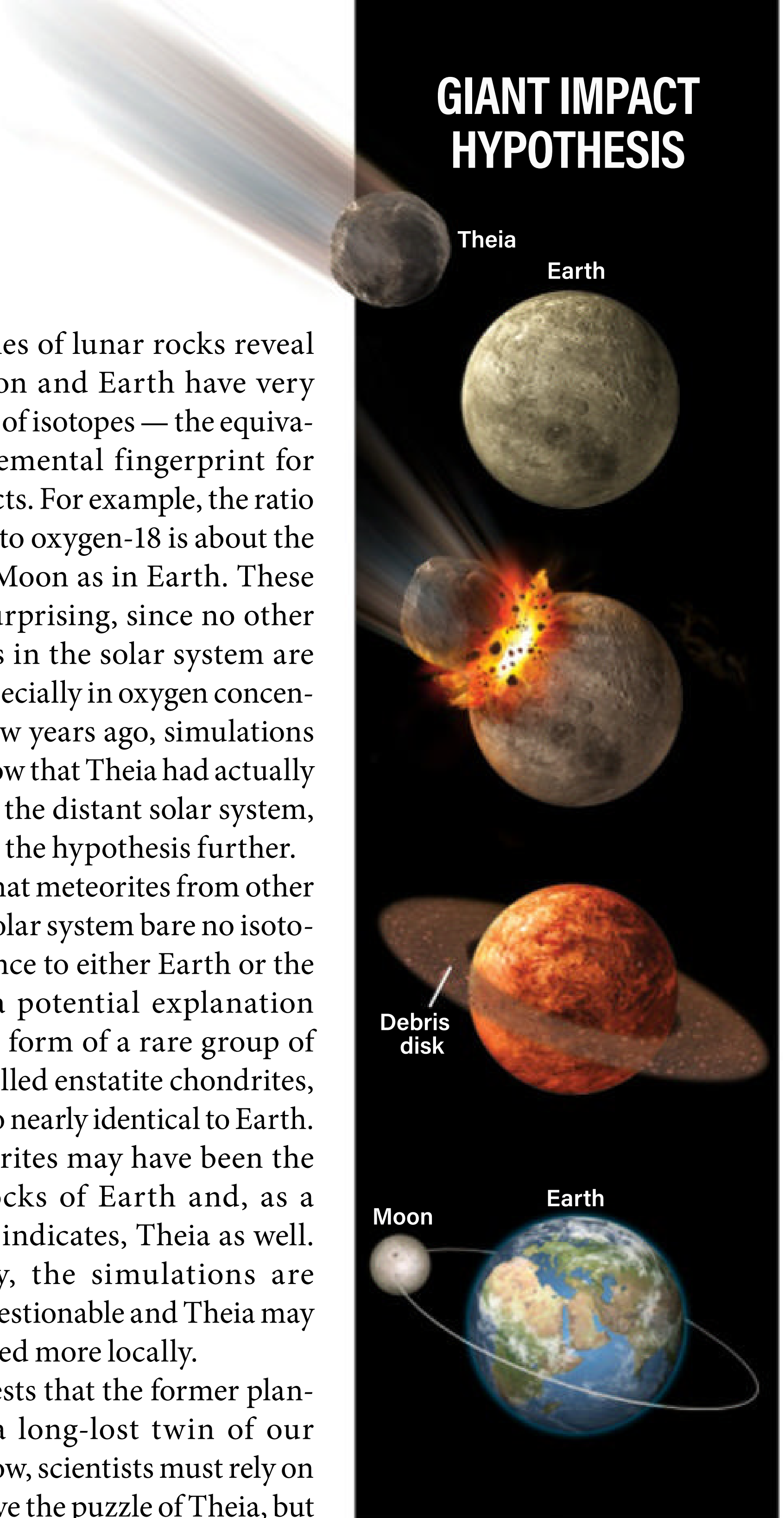
A | In the 1970s, Donald R. Davis and I suggested that the Moon was formed when a Mars-sized planetesimal, later called Theia, struck a newly formed Earth about 4.5 billion years ago. At the time, the Giant Impact Hypothesis had very little to say about what happened to the impactor itself.

In the years since, many researchers have modeled what the impact may have looked like. After slamming into Earth, the outer rocky shells of both Earth and Theia were blasted into a disk of debris around our planet. From this disk, the Moon coalesced; thus, models indicate most of Theia's material ended up as part of the Moon. Any iron core that Theia may have had was consumed by Earth's own core.

The Giant Impact Hypothesis is, as your question alludes to, not yet settled. One issue with the hypothesis

SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.



The Giant Impact Hypothesis suggests that some 4.5 billion years ago, a Mars-sized planetesimal dubbed Theia slammed into Earth. The impact sent chunks of both Earth and Theia into orbit around our young planet, eventually forming the Moon. ASTRONOMY: ROEN KELLY

is that samples of lunar rocks reveal that the Moon and Earth have very similar ratios of isotopes — the equivalent of an elemental fingerprint for celestial objects. For example, the ratio of oxygen-16 to oxygen-18 is about the same in the Moon as in Earth. These results are surprising, since no other major bodies in the solar system are that alike, especially in oxygen concentrations. A few years ago, simulations seemed to show that Theia had actually originated in the distant solar system, complicating the hypothesis further.

It is true that meteorites from other parts of the solar system bare no isotopic resemblance to either Earth or the Moon. But a potential explanation comes in the form of a rare group of meteorites called enstatite chondrites, which are also nearly identical to Earth. These meteorites may have been the building blocks of Earth and, as a recent paper indicates, Theia as well. Additionally, the simulations are somewhat questionable and Theia may have originated more locally.

This suggests that the former planetesimal is a long-lost twin of our planet. For now, scientists must rely on models to solve the puzzle of Theia, but if a stray meteorite from the collision is found, it may provide the final clues needed to put the mystery to rest.

William K. Hartmann
Senior Scientist Emeritus,
The Planetary Science Institute, Tucson, Arizona

Q | HAVE THERE BEEN ANY EXOPLANETS DISCOVERED IN GLOBULAR STAR CLUSTERS? IF SO, WOULD THEY BE QUITE RARE?

Wolfgang Golser
Tucson, Arizona

A | Globular clusters are compact, spherical collections of stars usually found in the halo of galaxies. The Milky Way is home to 150 known globular clusters. These clusters are much older and more densely packed with stars than their younger counterparts, open clusters, which means the two have very different environments for planet evolution.

In terms of finding exoplanets within globular clusters, researchers run into a problem: These clusters tend to be very far away. The closest globular cluster is M4, which is over 5,500 light-years away — 100 times farther than our nearest neighboring star and more than five times farther than the majority of exoplanets we've found so far. One method to find exoplanets is to watch for consistent dips in a star's brightness, which indicates that a planet is transiting, or passing in front of, the star from Earth's perspective. The farther away a star is, the dimmer it appears, which makes it harder to detect the even smaller dip in brightness of a transiting exoplanet.

But astronomers have managed to find one planet in a globular cluster: PSR B1620-26 (AB) b in M4. This planet is actually orbiting two stars, represented by the AB in the name. Those stars also happen to be pulsars — the leftover cores of long-dead stars, which emit very precisely timed radio pulses. When a planet is orbiting a pulsar, the exoplanet's gravity interferes with the timing of the radio pulses, which can be measured on Earth. (The very first exoplanets to ever be discovered were also found with this method.)

Of course, just because planets in globular clusters are hard to find does not mean they aren't common. Computer simulations indicate that, due to how many stars are packed close together in globular clusters, any planetary systems would also be compact. Close encounters with neighboring stars would fling planets in distant orbits similar to Jupiter and Saturn out into space. But planets with smaller orbits, like Mars or Earth, would be safe to keep circling their suns.

Dominique Petit dit de la Roche
graduate student,
European Southern Observatory,
Garching, Germany

Globular clusters are big groups of old stars that orbit the centers of their host galaxies. This cluster, NGC 121, belongs to the Milky Way's neighboring galaxy, the Small Magellanic Cloud. ESA/HUBBLE & NASA; ACKNOWLEDGEMENT: STEFANO CAMPANI

Cosmic portraits

1. LET FREEDOM SHINE
The Statue of Liberty Nebula (NGC 3576) ironically isn't visible from New York City because it lies in the southern constellation Carina the Keel. This massive star-forming region, which spans 100 light-years, lies 9,000 light-years from Earth.
• Nicholas Clarke

2. TUG OF WAR
With a diameter greater than half a million light-years, the Condor Galaxy (NGC 6872) in Pavo is one of the universe's largest known spirals. It is gravitationally interacting with IC 4970, the smaller lenticular galaxy above it. The pair lies 212 million light-years away.
• Nicolas Rolland

3. SCARS OF THE PAST
The large gouge at top center is Vallis Alpes (Latin for "Alpine Valley"), which bisects the Montes Alpes mountain range. It extends 104 miles (166 km). The crater Plato sits at the bottom, and Aristillus Crater lies at the right edge.
• John Chumack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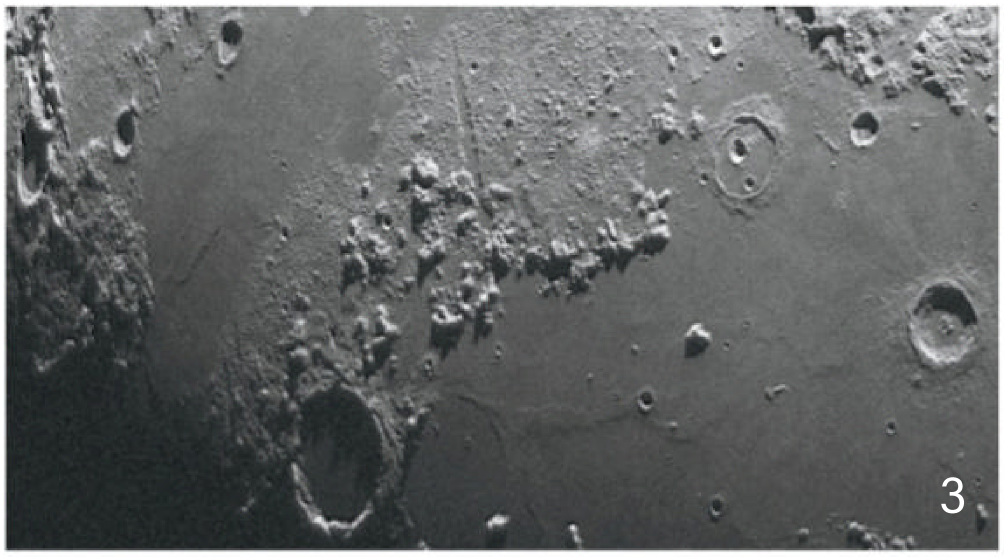
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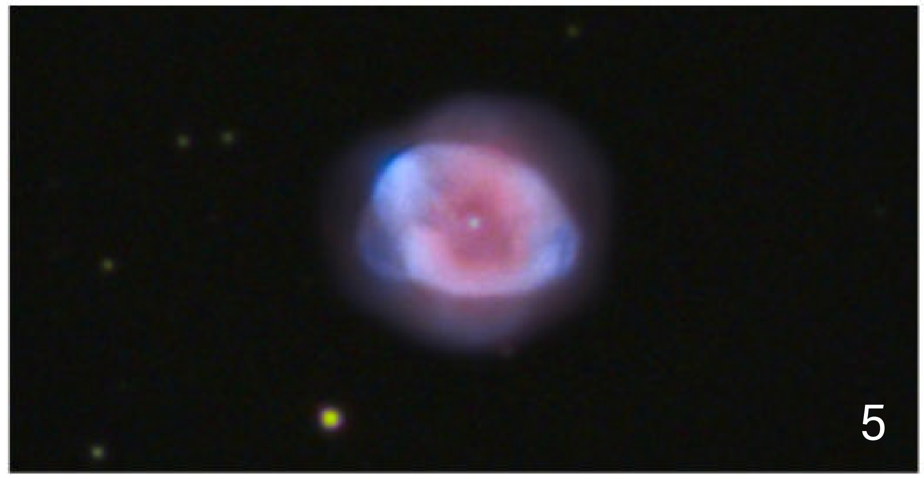

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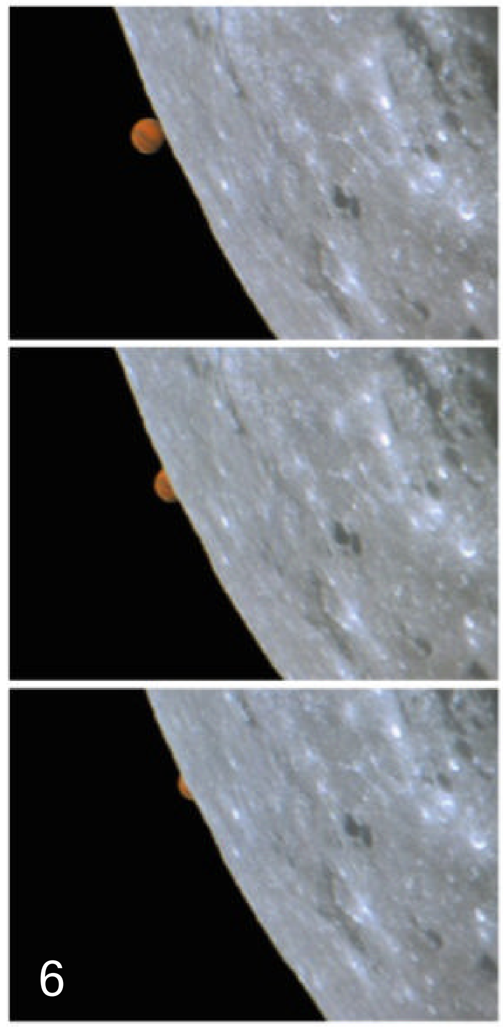

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4. MOMMY DEAREST
The statue The Mother, which lies on the northwestern coast of Aegina Island in Greece, symbolizes a woman who toils in devotion to her family. To create the star trails above it, this photographer captured 427 exposures of 45 seconds over 5.5 hours. ***• Anthony Ayiomamitis***

5. NO, NOT NEPTUNE
Planetary nebula IC 289 lies in the constellation Cassiopeia the Queen. It glows faintly at magnitude 13 and measures 35" across. This image combines 28.1 hours of exposure through a 6.5-inch refractor. ***• Douglas J. Struble***

6. THE GREAT COVER-UP
The Moon occulted Mars on September 6, 2020, from this imager's observatory in Brazil. This sequence of the immersion (disappearance) of the planet ran 1 minute 14 seconds, beginning at 3h02m34s UT. ***• Ricardo José Vaz Tolentino***

7. MYSTERIOUS SKY
The Loch Ness Monster Nebula lies in the constellation Vulpecula the Fox. Although it has a single common name, this region encompasses a star cluster, a reflection nebula, and 12 separate dark nebulae. ***• Chris Cook***

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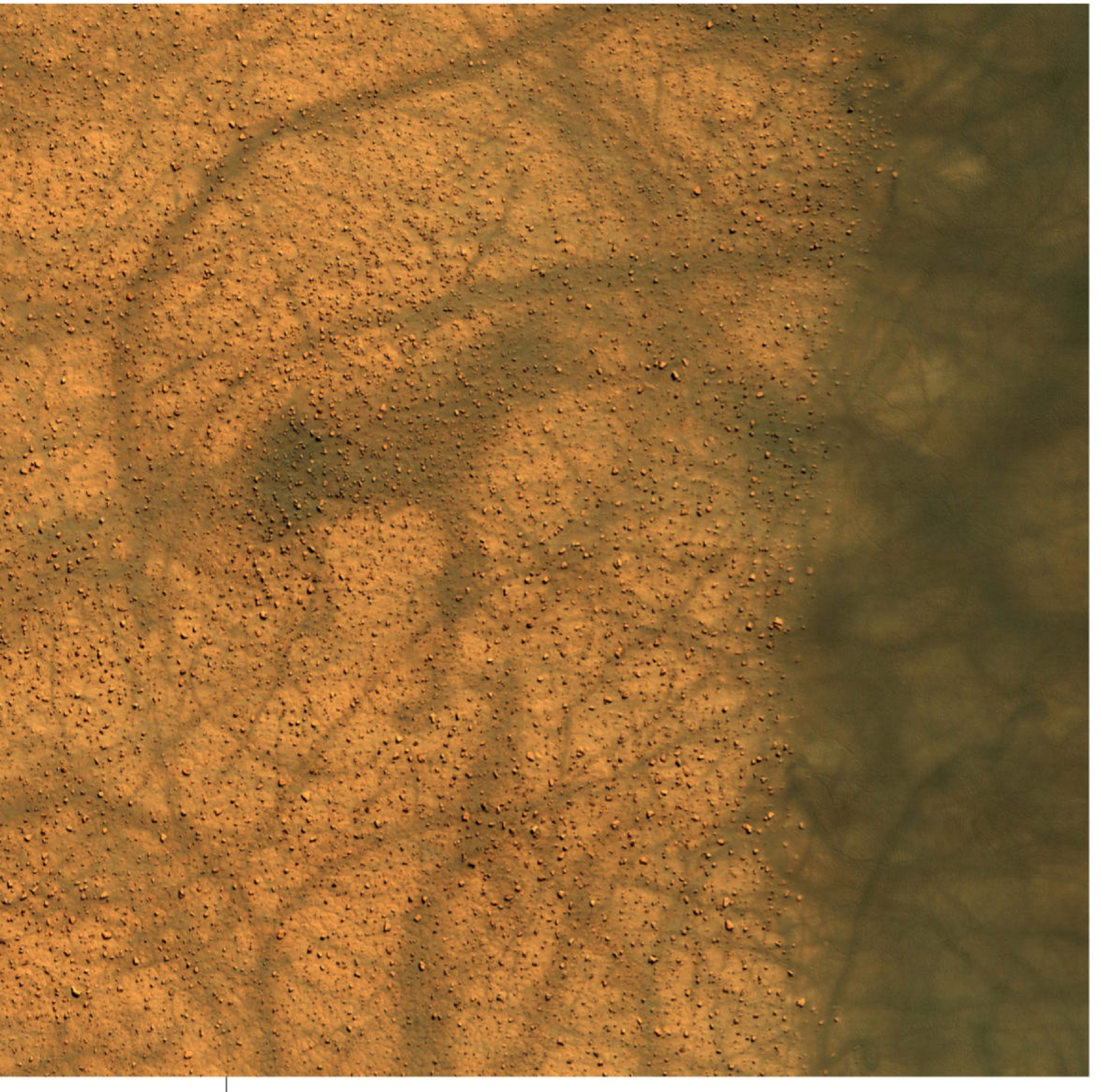


DANCE OF THE DUST DEVILS

Fifteen years ago this month, NASA's Mars Reconnaissance Orbiter reached the Red Planet and ushered in a new era in the exploration of Earth's neighbor. None of the spacecraft's instruments has been busier than the High Resolution Imaging Science Experiment, which has returned more than 7 million images showcasing surface details as small as 30 inches (75 centimeters) across. In this stunning example, dust-devil tracks appear etched into the bright, boulder-strewn plains surrounding the dark dune field at right. The dust devils form as the summer Sun warms the dunes. They then dance onto the plains, picking up bright dust particles and leaving behind the dusky trails. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

May 2021
Shadow play on the Moon

The orbital motions of the planets create a constantly changing skyscape. For example, Mars was the only planet visible in the evening hours during April. By late May, however, all five naked-eye planets are on display before midnight.

The first to show its face is ruddy **Mars**. It lies low in the northwest after darkness falls all month, appearing against the background stars of Gemini the Twins. In late May, the Red Planet stands near the bright stars Castor and Pollux, as if the three form a clock face reading 10 minutes before six o'clock. Mars then glows at magnitude 1.7, slightly fainter than the two stars. Enjoy the view with your naked eye — a telescope reveals only a depressingly bland disk just 4" across.

Mars welcomes its first company in mid-May when **Mercury** appears above the northwestern horizon during evening twilight. The innermost planet reaches greatest elongation on the 17th. It then lies 22° east of the Sun and stands 8° high a half-hour after sundown. Shining at magnitude 0.4, the planet should be obvious through binoculars to those with a clear and unobstructed horizon.

You'll want to keep an eye on the northwestern sky as the month progresses. As Mercury edges lower, brilliant **Venus** slowly climbs into view below it. The two planets are destined to meet May 29 when innermost Mercury passes 0.4° south of its neighbor. The two lie 6° high 30 minutes after sunset, with magnitude –3.9 Venus far easier to see against the twilight. A view through a telescope that evening shows Mercury's 11"-diameter disk and thin crescent phase while Venus spans 10" and appears nearly full.

All three of these planets set before 9 P.M. local time, leaving you a couple of hours to explore the deep sky before the next planets appear. **Saturn** rises first, poking above the eastern horizon just after midnight in early May and two hours earlier by month's end. The ringed world shines at magnitude 0.5 against the background stars of northern Capricornus.

Although a naked-eye sighting of Saturn is nice, nothing compares to the view through a telescope. In mid-May, the planet's disk measures 17" across while the rings span 39" and tilt 17° to our line of sight. A close look once Saturn climbs higher should reveal the dark gap of Cassini's Division, which separates the outer A ring from the brighter B ring. Several 10th-magnitude and brighter moons should also show up in the space surrounding the planet.

Jupiter rises nearly 90 minutes after Saturn from its perch in neighboring Aquarius. The giant planet gleams at magnitude –2.3 and dominates the night sky.

Wait until Jupiter climbs high in the east during the wee hours before pointing your telescope in its direction. Even the smallest scope reveals two dark atmospheric belts, one on either side of a brighter zone that coincides with the planet's 39"-diameter equator. Also watch for Jupiter's four bright moons, which change positions relative to one another from night to night and sometimes even from hour to hour.

May's biggest event takes place on the 26th when the Full Moon passes through Earth's dark umbral shadow against the backdrop of northern Scorpius. This total lunar eclipse favors observers in Australia and New Zealand. The partial phases of the eclipse run from 9h45m to 12h52m UT, while the 15 minutes of totality start at 11h11m UT.

The starry sky

At around 9 P.M. local time in mid-May, Crux the Cross stands highest in the south. Despite being the smallest of the 88 constellations, this grouping boasts many great binocular and telescopic sights. Last month I wrote of the splendor of Acrux, the Cross' brightest star and a beautiful double through a telescope.

This month I want to concentrate on some of Crux's outstanding binocular objects. The most popular one is the open star cluster called the Jewel Box, also known as NGC 4755 and the Kappa (κ) Crucis Cluster. The cluster lies near the eastern edge of Crux and shows a distinctive A shape when viewed with optical aid.

A more obscure target is one of my favorite double stars: Mu (μ) Crucis. The star lies in the constellation's northeastern corner, some 3.2° due north of the Jewel Box. Mu's primary glows at 4th magnitude while its 5th-magnitude companion stands 35" away. That's wide enough to split with steadily held 10x50 binoculars.

Just 3.2° west of Mu lies 2nd-magnitude Gacrux (Gamma [γ] Cru). Even a quick view of the constellation with the naked eye reveals Gacrux has a distinctly orange-red color, a stark contrast to the bluish hues of Crux's other bright stars. Binoculars gather enough additional light to show the red giant star's color even more clearly.

Another orange star within the Cross' confines is 4th-magnitude Epsilon (ε) Cru. Its fainter glow means you'll be hard-pressed to see any color without optical aid, though binoculars reveal it quite easily.

Our final target this month lies about halfway between Epsilon and Acrux. The open star cluster NGC 4349 isn't the showstopper that the Jewel Box is because it appears fainter and covers a slightly larger area. Still, binoculars show NGC 4349 well, and a telescope's added light-gathering power reveals its nice array of 10th-magnitude stars.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. May 1
8 P.M. May 15
7 P.M. May 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

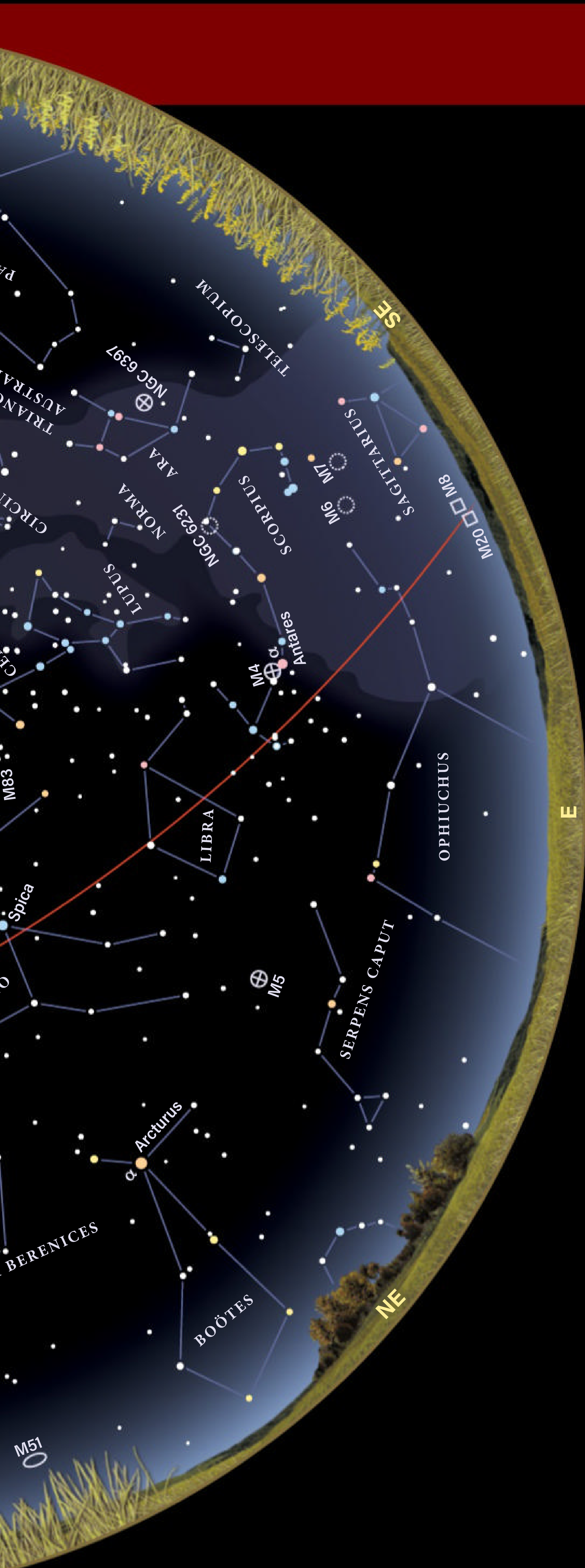
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



MAY 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

3 The Moon passes 4° south of Saturn, 17h UT

Last Quarter Moon occurs at 19h50m UT

4 The Moon passes 5° south of Jupiter, 21h UT

6 The Moon passes 4° south of Neptune, 18h UT

11 Mercury passes 8° north of Aldebaran, 3h UT

New Moon occurs at 19h00m UT

The Moon is at apogee (406,512 kilometers from Earth), 21h53m UT

12 The Moon passes 0.7° south of Venus, 22h UT

13 The Moon passes 2° south of Mercury, 18h UT

16 The Moon passes 1.5° north of Mars, 5h UT

17 Mercury is at greatest eastern elongation (22°), 6h UT

Venus passes 6° north of Aldebaran, 23h UT

19 First Quarter Moon occurs at 19h13m UT

23 Saturn is stationary, 20h UT

26 The Moon is at perigee (357,311 kilometers from Earth), 1h50m UT

Full Moon occurs at 11h14m UT; total lunar eclipse

29 Mercury passes 0.4° south of Venus, 6h UT

30 Mercury is stationary, 2h UT

31 The Moon passes 4° south of Saturn, 1h UT